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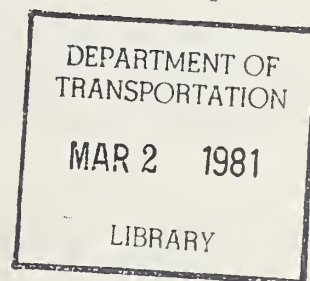
IDENTIFICATION OF THE FIRE THREAT IN URBAN TRANSIT VEHICLES

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U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142



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FINAL REPORT



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16. Abstract The study presented includes on-site surveys of the 1978 calendar year experience of nine representative U.S. transit authorities. Analyses of the data collected and of the fault tree for bus and rail rapid transit vehicle fires allow for the identification of potential ignition sources and path of fire propagation. There is also a discussion of the approach to the selection of countermeasures to minimize and, where possible, to eliminate fire threats in transit vehicles.					
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PREFACE

The Urban Mass Transportation Administration (UMTA) in its mission of improving mass transportation is examining the present situation with respect to the fire threat in order to develop countermeasures and fire safety standards for transit vehicles. It is expected that ever larger numbers of people will be using mass transportation and that ever greater demands will be placed on mass transportation vehicles. It is important that fire safety not be overlooked by mass transit properties or by manufacturers of mass transit vehicles in their efforts to answer the growing demands.

This report is an attempt to identify potential sources of ignition and likely fire paths on transit vehicles together with probabilities of occurrence in order that priorities for countermeasures can be determined. It is hoped that this report will be a significant contribution in helping UMTA to achieve these important objectives.

The authors wish to thank William J. Rhine and Robert I. Haught of UMTA for their valuable guidance and comments over the course of this work. They also wish to acknowledge the important contributions of the following individuals: Herbert L. Bogen and Stephanie Markos, Raytheon Service Co., and Robert Anderson, formerly of Raytheon Service Co. and presently a member of the TSC staff, for their efforts in data collection and analysis; C.E. Bogner for his input to Section 4 and I. Litant and A.E. Barrington also of TSC. The authors wish especially to thank the chief executive officers of the transit properties surveyed and their staffs for their help and cooperation in the collection of the data of this report. The many helpful conversations with these individuals were of considerable help in the completion of this report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

When You Know Multiply by To Find

Symbol

Symbol

LENGTH

in	inches	2.5	cm	centimeters
ft	feet	30	cm	centimeters
yd	yards	0.9	m	meters
mi	miles	1.6	km	kilometers

AREA

m ²	square inches	6.5	cm ²	square centimeters
ft ²	square feet	0.09	m ²	square meters
yd ²	square yards	0.8	m ²	square meters
mi ²	square miles	2.6	km ²	square kilometers
	acres	0.4	ha	hectares

MASS (weight)

oz	ounces	28	g	grams
lb	pounds	0.45	kg	kilograms
	short tons	0.9	t	tonnes
	(2000 lb)			

VOLUME

tsop	tablespoons	5	ml	milliliters
fl oz	fluid ounces	30	ml	milliliters
c	cups	0.24	l	liters
pt	pints	0.47	l	liters
qt	quarts	0.95	l	liters
gal	gallons	3.8	l	liters
ft ³	cubic feet	0.03	m ³	cubic meters
yd ³	cubic yards	0.76	m ³	cubic meters

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	°C	Celsius temperature
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Approximate Conversions from Metric Measures

When You Know Multiply by To Find

Symbol

Symbol

LENGTH

mm	millimeters	0.04	in	inches
cm	centimeters	0.4	in	inches
m	meters	3.3	ft	feet
m	meters	1.1	yd	yards
km	kilometers	0.6	mi	miles

AREA

cm ²	square centimeters	0.16	in ²	square inches
m ²	square meters	1.2	yd ²	square yards
km ²	square kilometers	0.4	mi ²	square miles
ha	hectares (10,000 m ²)	2.5	acres	acres

MASS (weight)

g	grams	0.035	oz	ounces
kg	kilograms	2.2	lb	pounds
t	tonnes (1000 kg)	1.1		short tons

VOLUME

ml	milliliters	0.03	fl oz	fluid ounces
l	liters	2.1	pt	pints
l	liters	1.06	qt	quarts
m ³	cubic meters	0.26	gal	gallons
m ³	cubic meters	36	ft ³	cubic feet
m ³	cubic meters	1.3	yd ³	cubic yards

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	°F	Fahrenheit temperature
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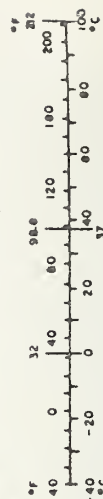


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1. INTRODUCTION

The Transportation Systems Center (TSC) has been tasked by the Urban Mass Transportation Administration (UMTA) to assess the overall fire threat in transit systems and to identify and recommend suitable remedial actions. This report presents the identification of the fire threat in urban transit vehicles. The potential threat of fire in transit vehicles is well recognized. However, the quantification of actual occurrences, rates, losses, etc. is extremely limited. In addition, little formal analysis has been done on the conditions and events that result in the initiation and spread of fire and smoke in transit vehicles. The data that exist are generally internal operating information for individual transit properties; little additional data are generated for external use.

This report serves to fill some of the gaps in knowledge. It is based on site visits to nine representative transit properties during which data were obtained from daily logs, operator reports, accident reports, police reports, and maintenance reports. [Information from nine other properties was obtained by mailed-out questionnaires.] To the best of our knowledge, this is the most complete and accurate information currently available on fire and smoke incidents in urban mass transit vehicles.

These data are supplemented by fault tree diagrams and scenarios in identification of the fire threat. These are based on actual transportation fire and smoke incidents in TSC files, data analysis, interviews with transit personnel, and the use of maintenance manuals. Following a description of the TSC data acquisition methodology, the data are analyzed and discussed along with the relationship of the fault trees and scenarios to the identification of countermeasures.

2. TRANSIT DATA ACQUISITION METHODOLOGY

The initial TSC effort to establish the number and nature of fire and smoke incidents in transit vehicles consisted of a survey of several data sources. These included the data banks maintained by the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS), the National Fire Protection Association's Fire Incident Data Organization (FIDO), the National Transportation Safety Board, the Federal Highway Administration's Bureau of Motor Carrier Safety and the Federal Railroad Administration's data reporting system (now maintained by UMTA as the "Rail Accident/Incident Report"). The information available from these sources was found to be limited in volume and detail and insufficient for this investigation. For a detailed review of all the available data banks containing fire and smoke data, the reader is referred to Reference 1. Most of the data sources contained either too few incidents or only the large or well known incidents. Examples of some of the data found are contained in Appendix A.

Because of these limitations, it was necessary to establish direct contact with the transit properties. Transportation Systems Center personnel visited nine representative properties to obtain data on frequency and type of fire/smoke incidents experienced. The site visits were made to the Massachusetts Bay Transportation Authority (MBTA), the New York City Transit Authority (NYCTA), the Bay Area Rapid Transit District (BART), the San Francisco Municipal Railway (MUNI), the Southern California Rapid Transit District (RTD-Los Angeles), the Denver Rapid Transit District (RTD-Denver), the Metropolitan Atlanta Rapid Transit Authority (MARTA), the Washington Metropolitan Area Transit Authority (WMATA), and the Chicago Transit Authority (CTA). Other properties responded with information through the

mail: the Port Authority of Allegheny County (Pittsburgh), the Greater Cleveland Regional Transit Authority (RTA), the City of Detroit--Department of Transportation, Transport of New Jersey (TNJ), the Mass Transit Administration (MTA-Baltimore), the Tri-County Metropolitan Transit District of Oregon (TRI-MET), the Southeastern Pennsylvania Transit Authority (SEPTA), the Transit Authority of River City (TARC-Louisville) and the Toronto Transit Commission. This information obtained by mail was not used in this report because it was felt that it did not reflect all the smoke and fire incidents for 1978.

It was found during the site visits that incidents are recorded in daily logs, similar to the one presented in Fig. 2.1, located at a central control center. Depending on the severity of the incident, follow-up reports may be filed. The amount of information recorded in the daily logs and the availability of follow-up reports varied among the transit properties. Usually the information recorded included:

- date and time of incident
- vehicle number and operator identification
- location of vehicle at time of incident
- delay in service and damage
- action taken.

The daily logs were handwritten, usually in tabular format. Typically, description of incidents lacked the degree of detail necessary for complete comprehension by personnel not familiar with day-to-day operational events at that property. It was often necessary to obtain clarification of accident descriptions from operating personnel, either because of local jargon used or because of brevity of remarks.

The data collected from the nine transit properties represented all bus and rail rapid transit (RRT) fire and smoke incidents which occurred at those transit properties during the calendar year 1978.

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FIGURE 2.1 SAMPLE DAILY LOG

3. DEFINITION OF THE FIRE THREAT

The purpose of this section is to define in quantitative and qualitative terms the fire threat in transit vehicles. Actual fire incident data gathered from the transit properties, as discussed in Section 2. and 3.1, are used to quantify the fire threat. Scenarios and fault trees are used as a supplement to the incident data and define the fire threat in a qualitative manner. Defining the fire threat in these terms will allow for the identification of all prospective countermeasures and will assist in determining the priorities for their implementation.

Section 3.1 is an analysis of the data collected from the transit properties and Sections 3.2 and 3.3 discuss the fault trees and scenarios and their relationships, respectively.

3.1 DATA ANALYSIS

As discussed in Section 2., several sources of data were examined with the final result being a detailed survey of the records of nine transit properties. The data discussed in this section are limited to that from the nine transit properties. It should be recognized that uncertainties in interpretation of this type of data are inevitable as they are gathered from sources using to some extent, different procedures of collection and different methods and emphasis on records maintenance.

The data are aggregated, as shown in Figures 3.1 and 3.2, since the objective is to obtain the overall frequency distribution for all nine transit properties rather than to make comparisons between properties. Incidents are presented on the basis of occurrence per million vehicle miles. The nine transit properties for which the data of Figs. 3.1 and 3.2 apply reported a total of 417 million bus revenue miles and 331 million rail rapid transit revenue miles in 1978. During this

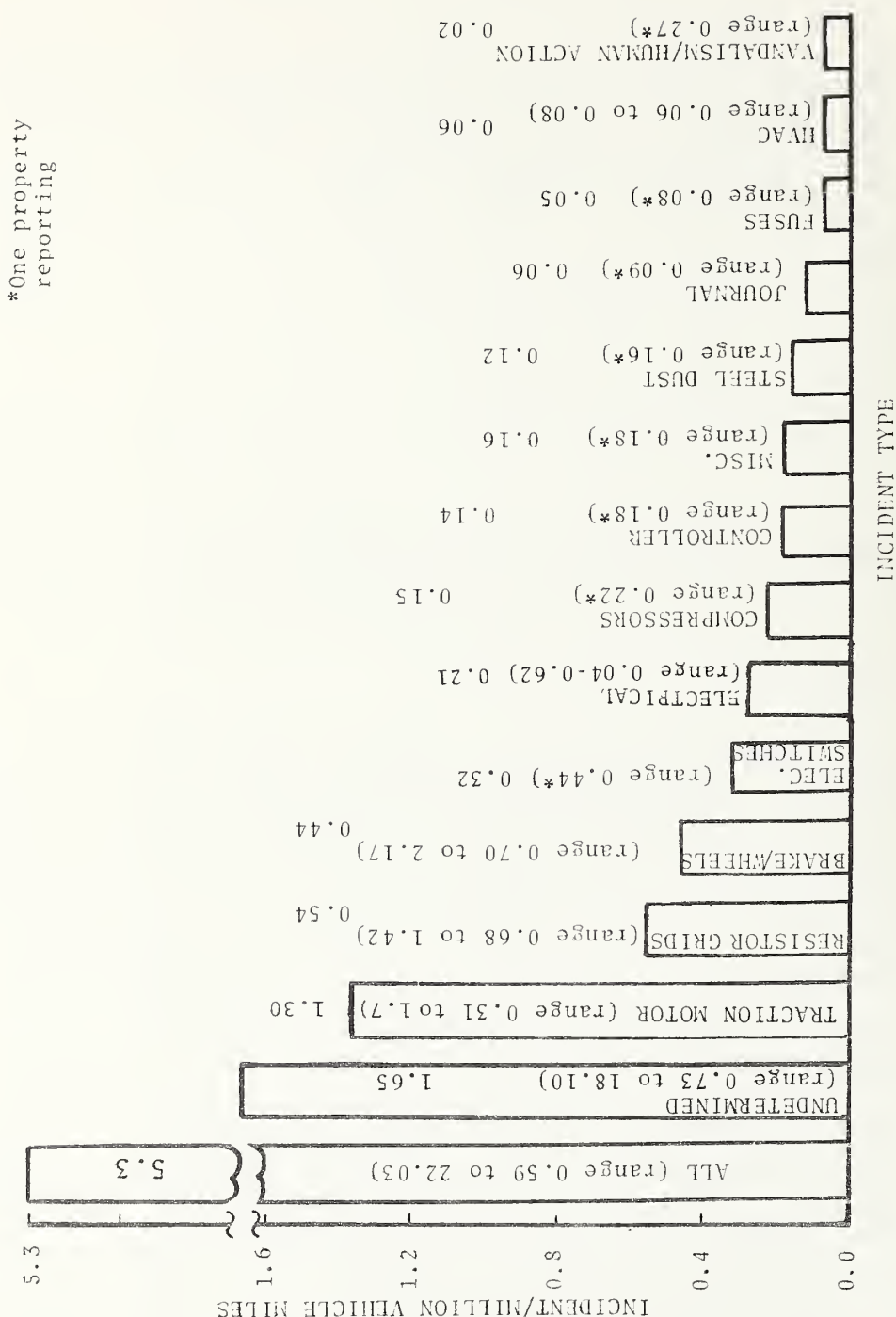


FIGURE 3.1 RAIL RAPID TRANSIT FIRE/SMOKE INCIDENT RATE (1978 DATA)

*One property reporting

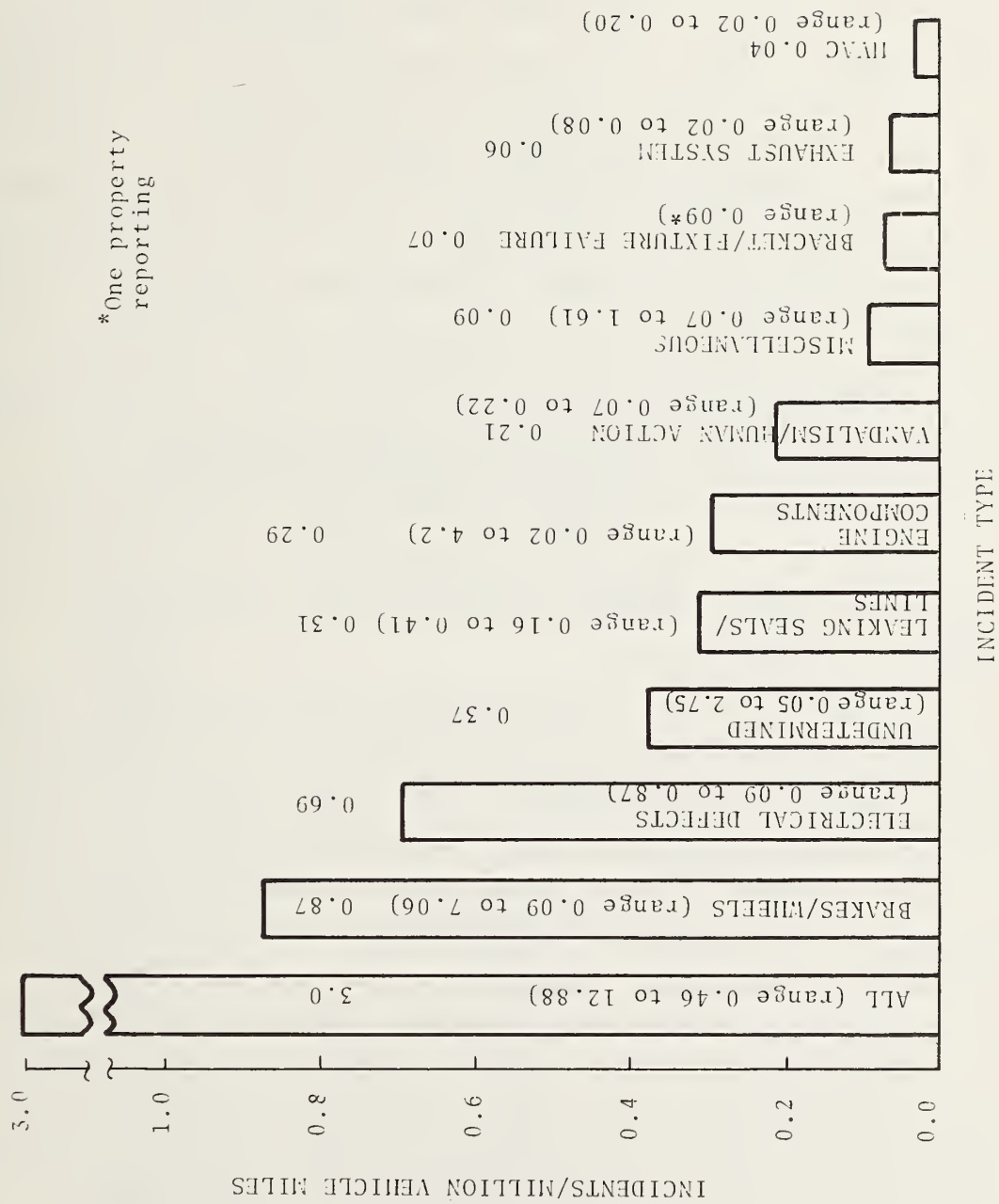


FIGURE 3.2 BUS FIRE/SMOKE INCIDENT RATE (1978 DATA)

period 1246 bus and 1742 rail rapid transit fire and smoke incidents were reported in the records of the nine transit properties. This yields 3.0 fire and smoke incidents per million bus-miles and 5.3 fire and smoke incidents per million rail rapid transit miles. As noted above, these incident rates are for the overall transit community and the range of incident rates for the individual properties varied considerably and are also shown in Figures 3.1 and 3.2. In many cases incident reports stated that fire or smoke had occurred but did not provide any further details; these incidents are tabulated under "undetermined." Several transit properties reported the service delay caused by the accident and these data are shown in Figures 3.3 and 3.4. The repair costs for fire and smoke damaged vehicles was reported by only one transit property and is plotted in Figure 3.5. As might be expected, the cost of repair of the vehicle varies with the frequency of occurrence; i.e., incidents which resulted in inexpensive damage had a high frequency of occurrence.

In the process of on-site examination of the transit property records, it was noted that the number of fire and smoke incidents were vastly outweighed by the total number of other types of on-board incidents. They included mechanical failures without fire or smoke, crashes, passenger injuries and fatalities, passengers falling or becoming sick in the vehicle, altercations of some type, vandalism, etc. As an example, at one bus property there were a total of 4000 incidents reported in 1978 of which, only 50 were fire and smoke incidents. Generally, it was found that fire and smoke incidents in buses represented approximately two percent of the total bus incidents. For rail rapid transit, the percentage of all incidents in which fire and smoke are involved is estimated by TSC to vary between one and five percent. These percentages represent the best estimates available and are limited by the difficulty in estimating the total number of incidents and also the variances in the

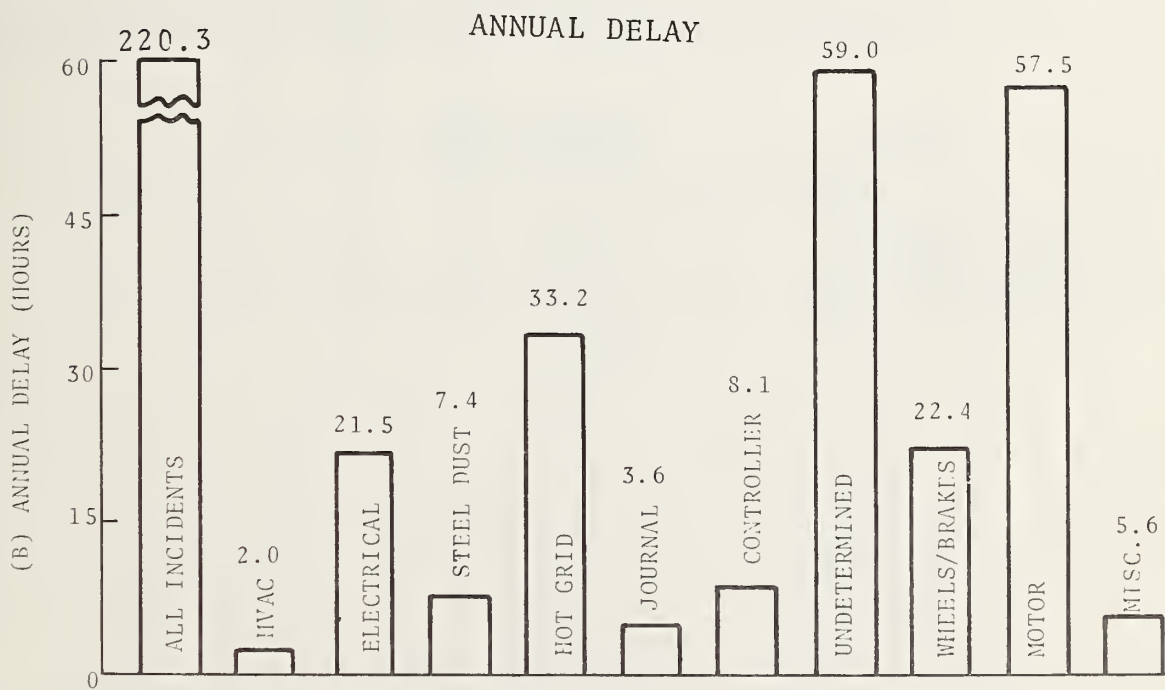
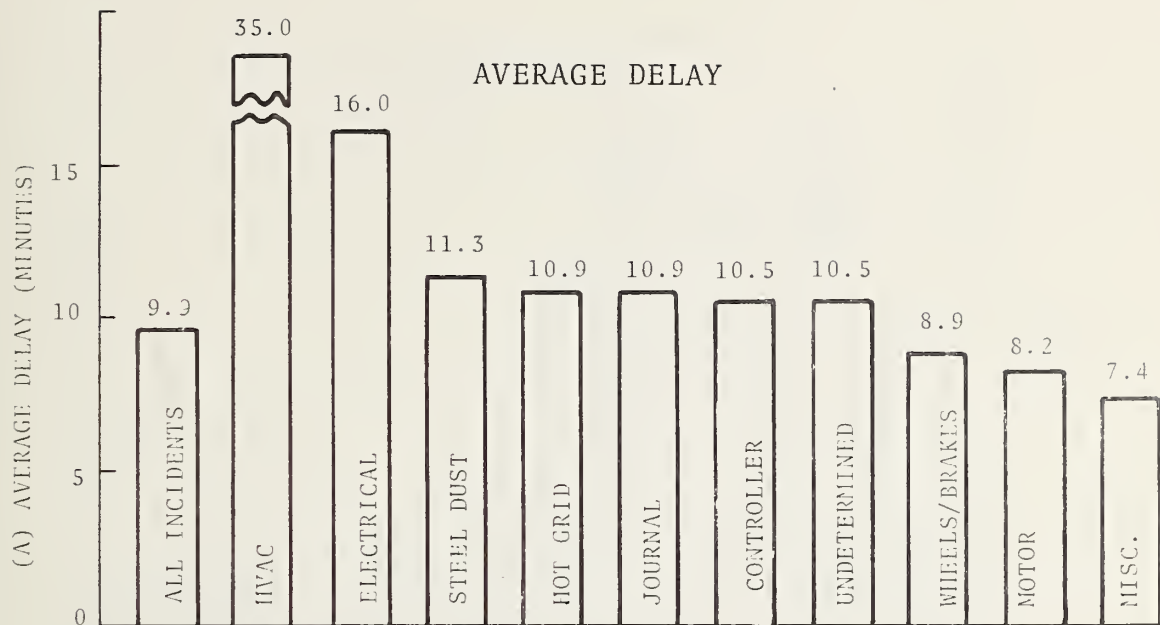


FIGURE 3.3 SERVICE DELAY BY INCIDENT TYPE--RRT
(DATA FROM 3 PROPERTIES) (1978 DATA)

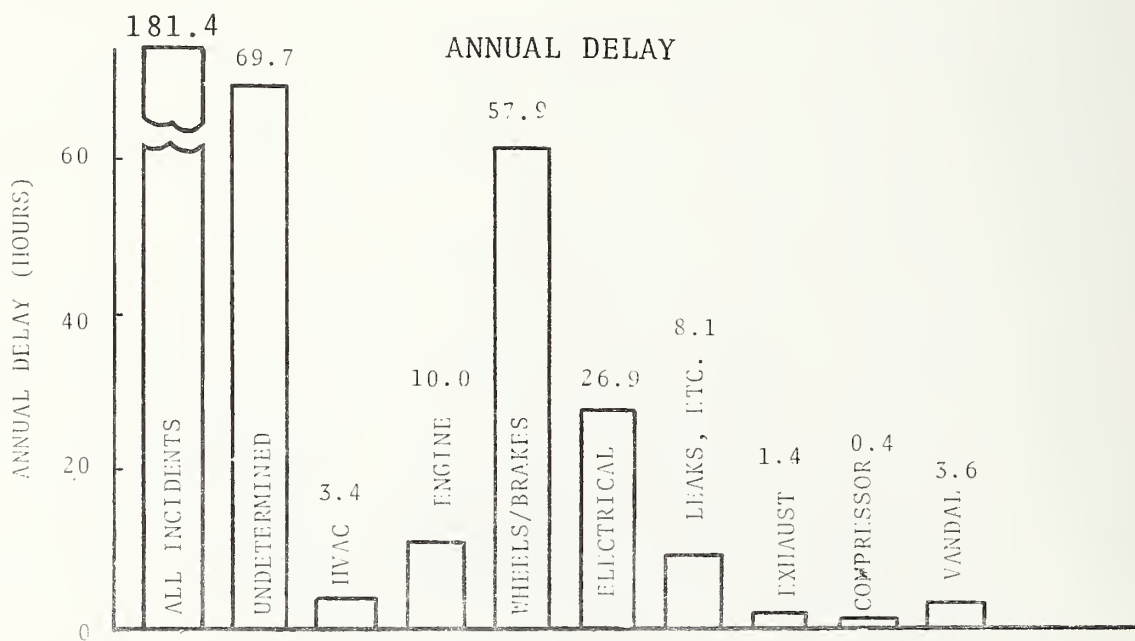
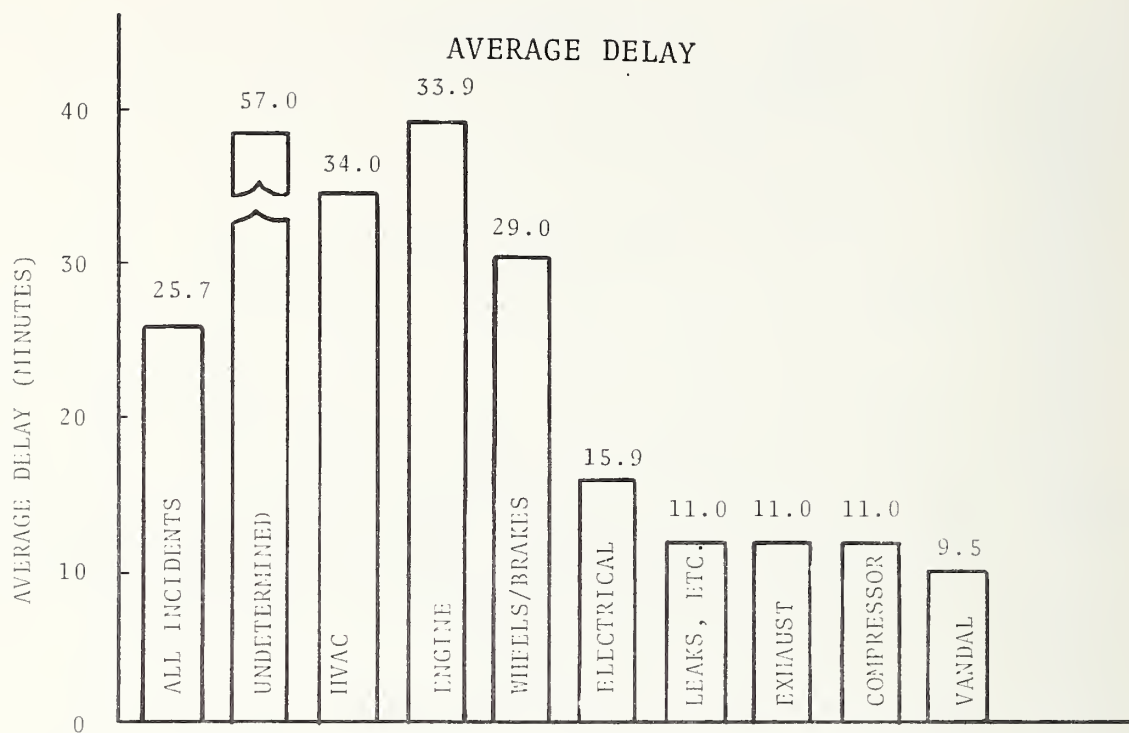


FIGURE 3.4 SERVICE DELAY BY INCIDENT TYPE--BUS
(DATA FROM 4 PROPERTIES) (1978 DATA)

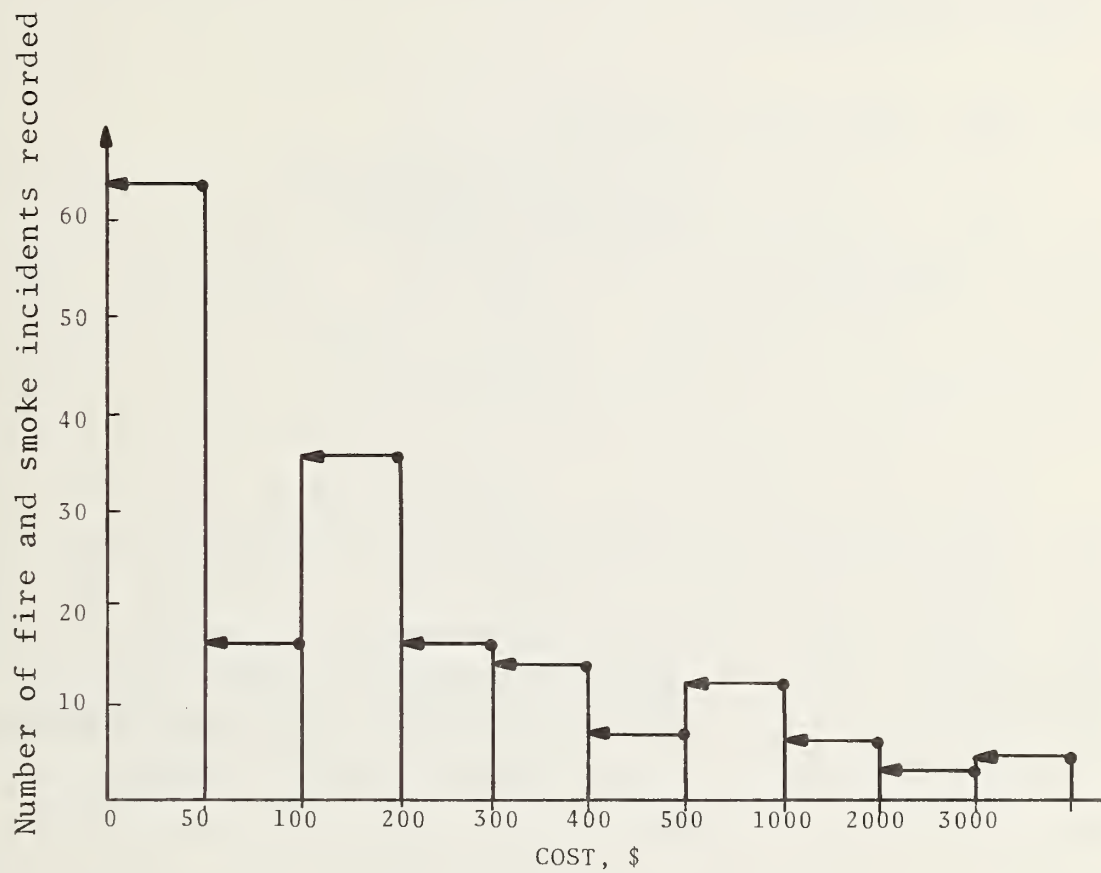


FIGURE 3.5 COST OF REPAIR DATA FROM ONE BUS PROPERTY, NUMBER OF FIRE AND SMOKE INCIDENTS VS. COST (1978 DATA)

reporting practices of the transit properties. The comparatively low rate of occurrence of fire and smoke incidents leads one to expect these represent a hazard fairly low on their list of problems to be dealt with. Although this may be true, it should be noted that each minor incident has the potential to become a major incident which may result in extensive loss of life and property.

3.2 FAULT TREES AND SCENARIOS

This section discusses the use of fault trees and scenarios as a means of qualitatively presenting how minor incidents occur and how they may become major incidents. Fault trees and scenarios will also allow for the identification of prospective countermeasures to eliminate the occurrence of an incident or to insure that a minor incident does not develop any further.

Fault tree analysis is a technique which provides a graphical representation of the relationship between certain specific events and the undesired or head event. As an example, Figure 3.6, shows a fault tree for a fire or smoke incident in a bus brake system. The "Fire/Smoke in Brake System" is the undesired or head event and the secondary events which may lead to the head event are "slack adjustor fails," "brake chamber push rod fails," or "other." The events are connected by "gates." An "OR" gate, as shown in Figure 3.6, requires that at least one of the secondary events occur in order for the head event to occur. An "AND" gate, as shown in Figure 3.7, requires that all secondary events must occur before the head event occurs. Reference 2 provides a more detailed discussion of fault tree analysis.

Simple trees, such as those of Figures 3.6 and 3.7, may be linked together to form larger trees. Fault trees may be qualitative, quantitative, or both, since; once the tree is fully developed in a qualitative manner, it is possible to determine the

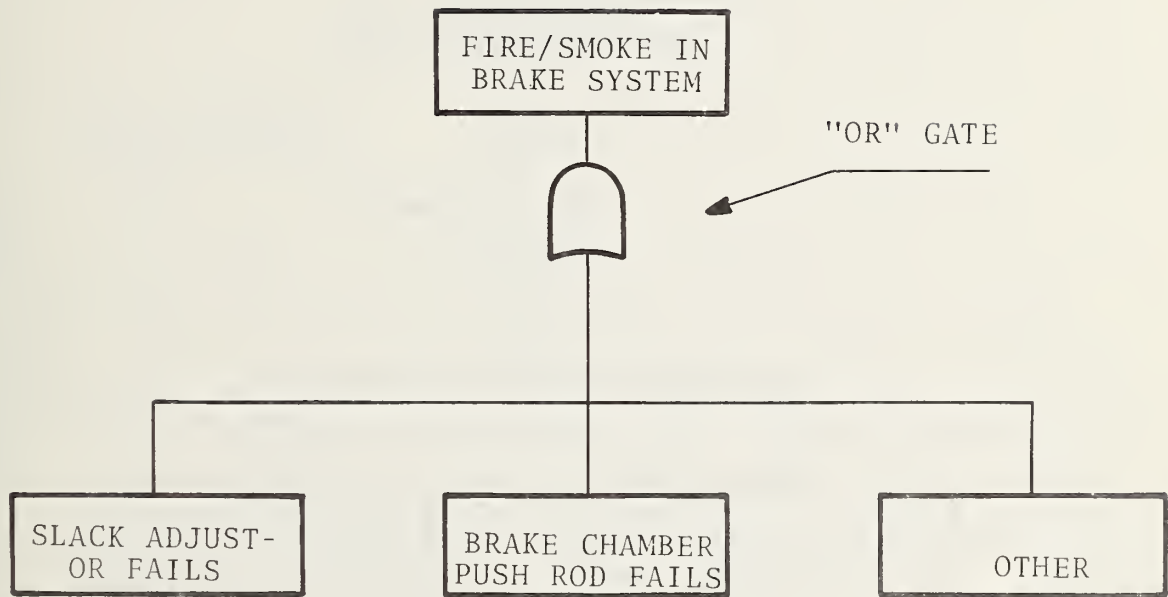


FIGURE 3.6 USE OF THE "OR" GATE

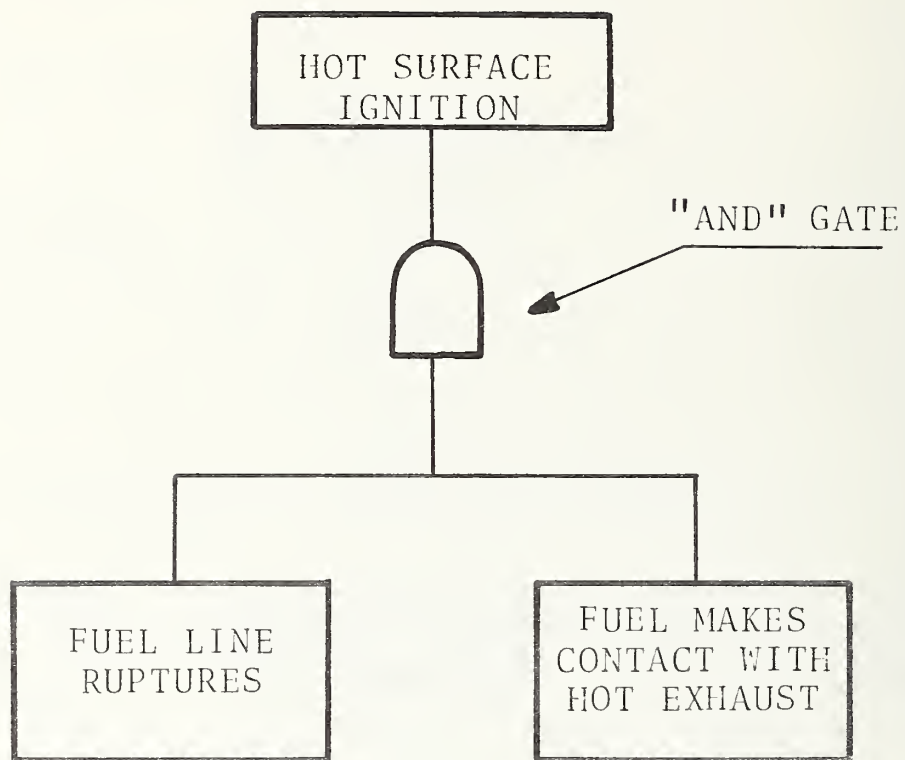


FIGURE 3.7 USE OF THE "AND" GATE

probability of occurrence of the head event. This is done by assigning values for the probability of occurrence or frequency of the secondary events and then calculating the probability of the head event occurring. These probabilities of occurrence then allow the ranking of various sequences by their probability of occurrence and provide the necessary base for decisions as to where countermeasures will result in the greatest return in saving of lives and property. The data of Section 3.1 are limited in type and detail of occurrence and, therefore, may represent only a small portion of the possible fire and smoke threats. Fault tree analysis will lead to the identification of other possible events and combinations of events which might not otherwise be recognized from the data, as potential causes of the head event. Furthermore, when working with historical data to predict the future occurrence of incidents, only those incidents which have occurred in the past and are in the historical data base may be projected to occur in the future. Incidents which have yet to occur may not be identified as possible future threats. The fault trees shown in Figures 3.8 and 3.9 represent smoke and fire incidents in rail rapid transit cars and buses, respectively. These fault trees, along with more detailed ones, will be used to identify the countermeasures necessary to minimize, and, where possible, to eliminate the fire threat in transit vehicles.

To supplement the fault trees, scenarios were developed to provide a detailed description of the fire and smoke initiation and propagation as well as the responses and actions of the vehicle occupants. Each of the scenarios corresponds to an event sequence in the fault trees.

A list of scenarios developed is given in Table 3.1 for RRT vehicles and in Table 3.2 for buses. The frequency of occurrence, obtained from Figures 3.1 and 3.2, of each scenario type is also listed as well as relative percentage of incidents.

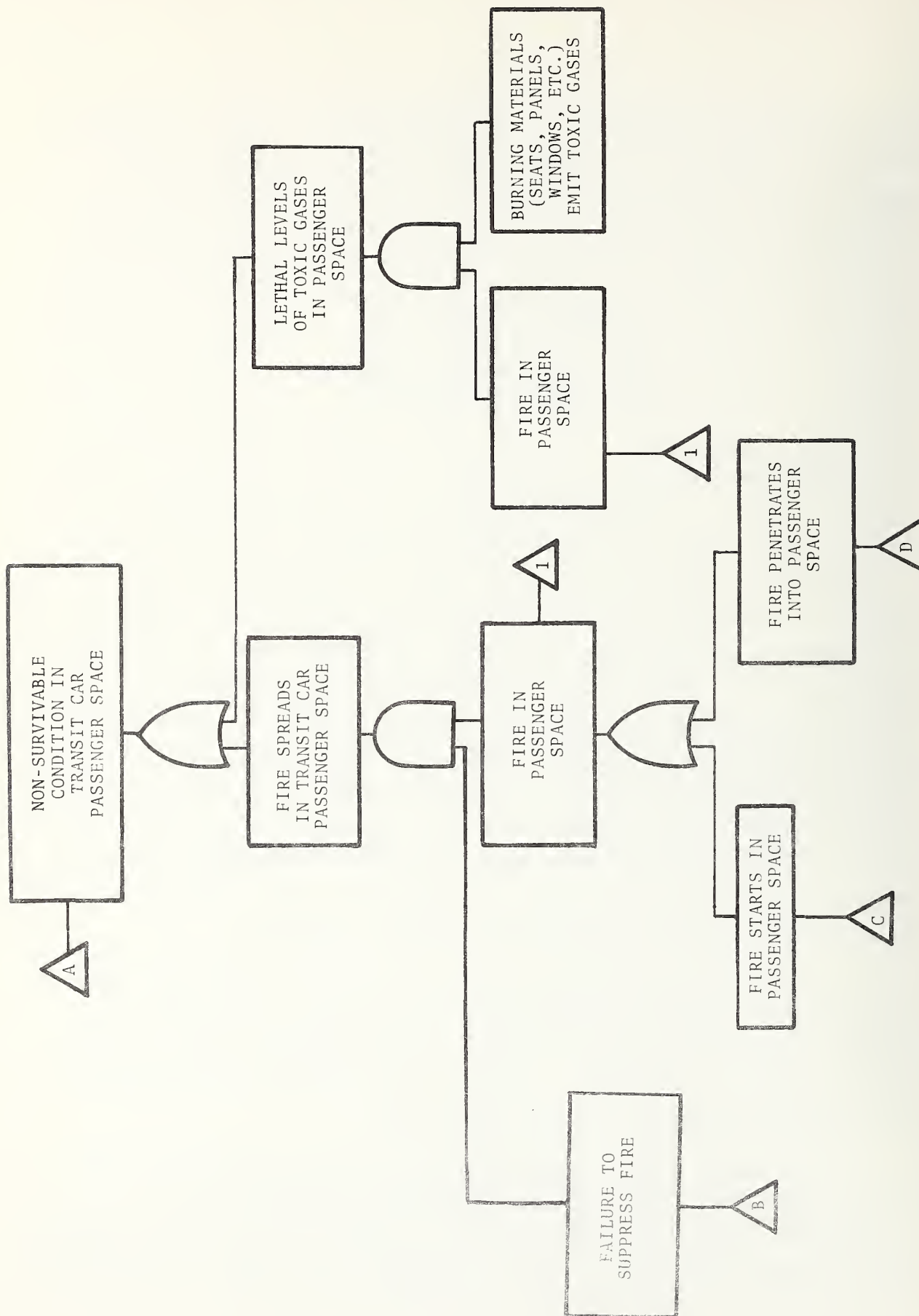


FIGURE 3.8.1 FAULT TREE A, RAIL RAPID TRANSIT VEHICLE FIRE

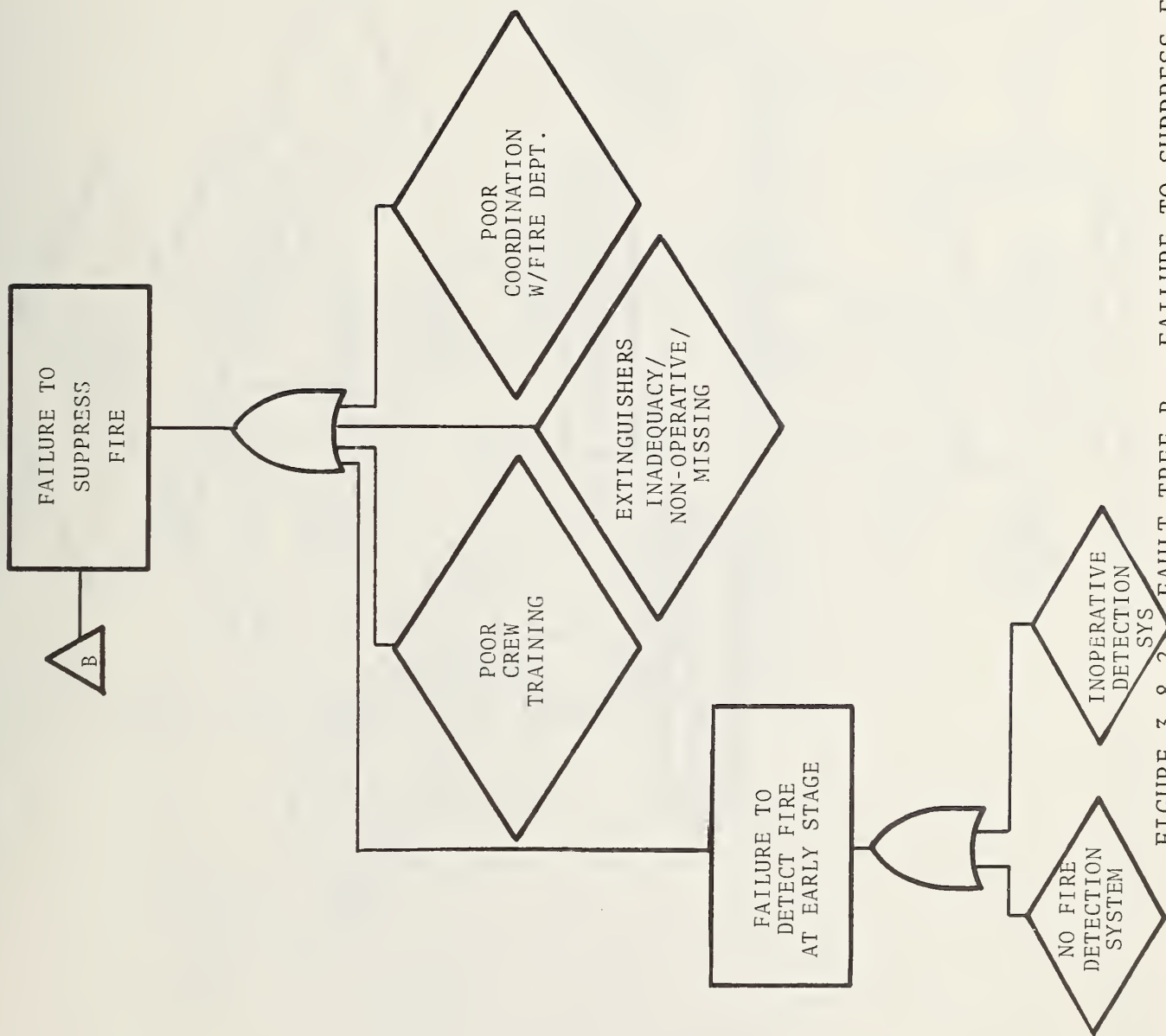


FIGURE 3.8.2 FAULT TREE B, FAILURE TO SUPPRESS FIRE

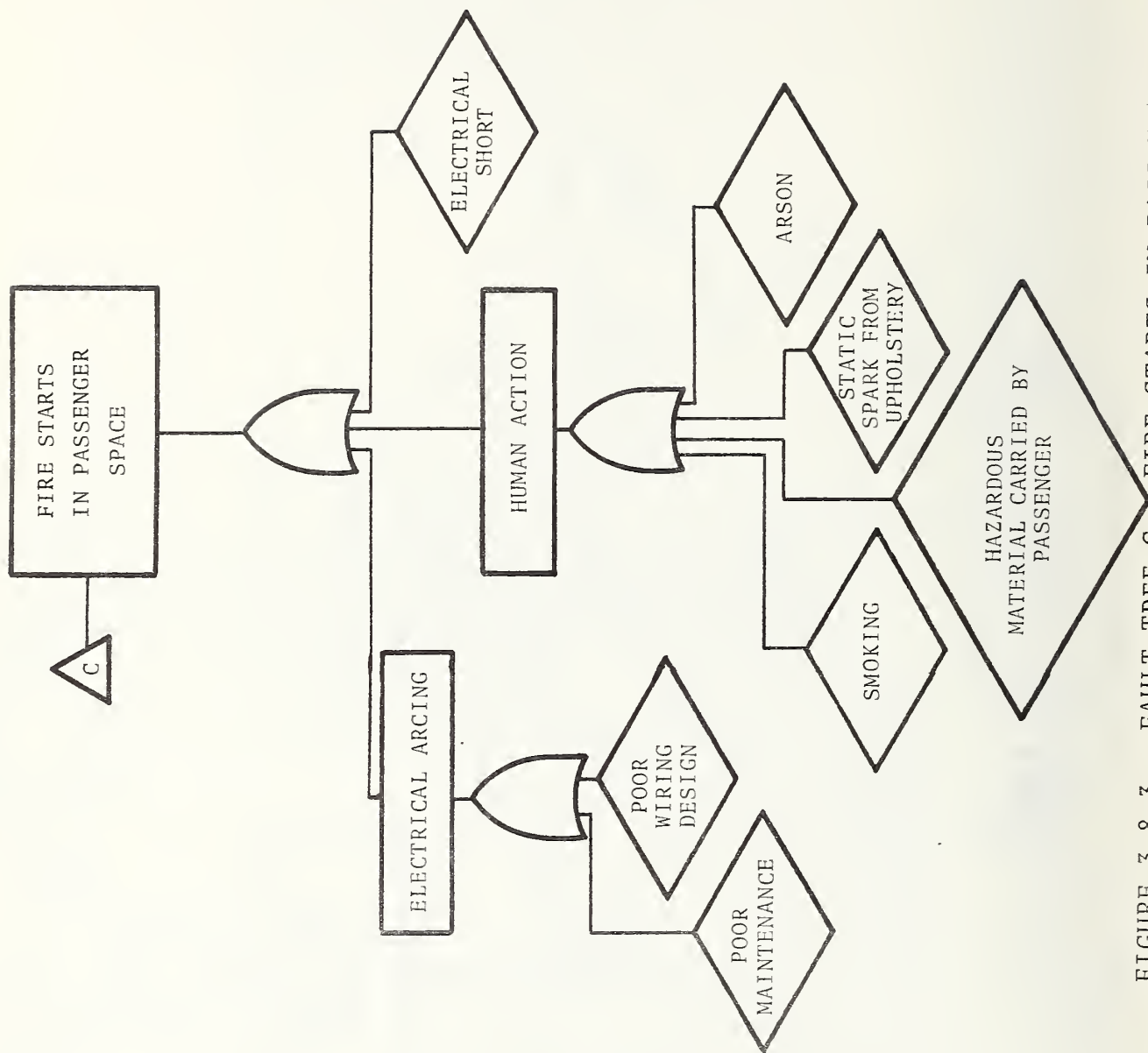
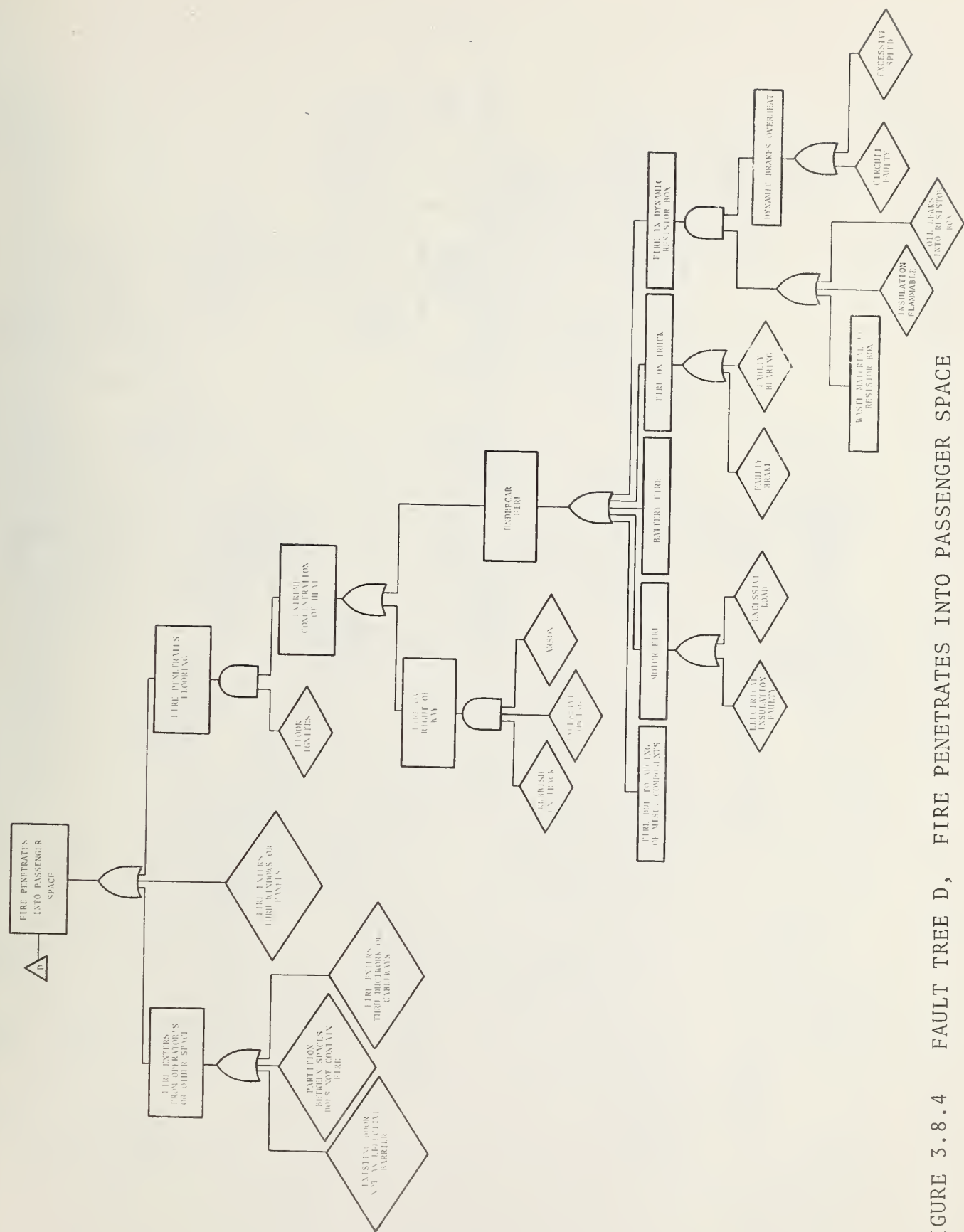


FIGURE 3.8.3.3 FAULT TREE C, FIRE STARTS IN PASSENGER SPACE



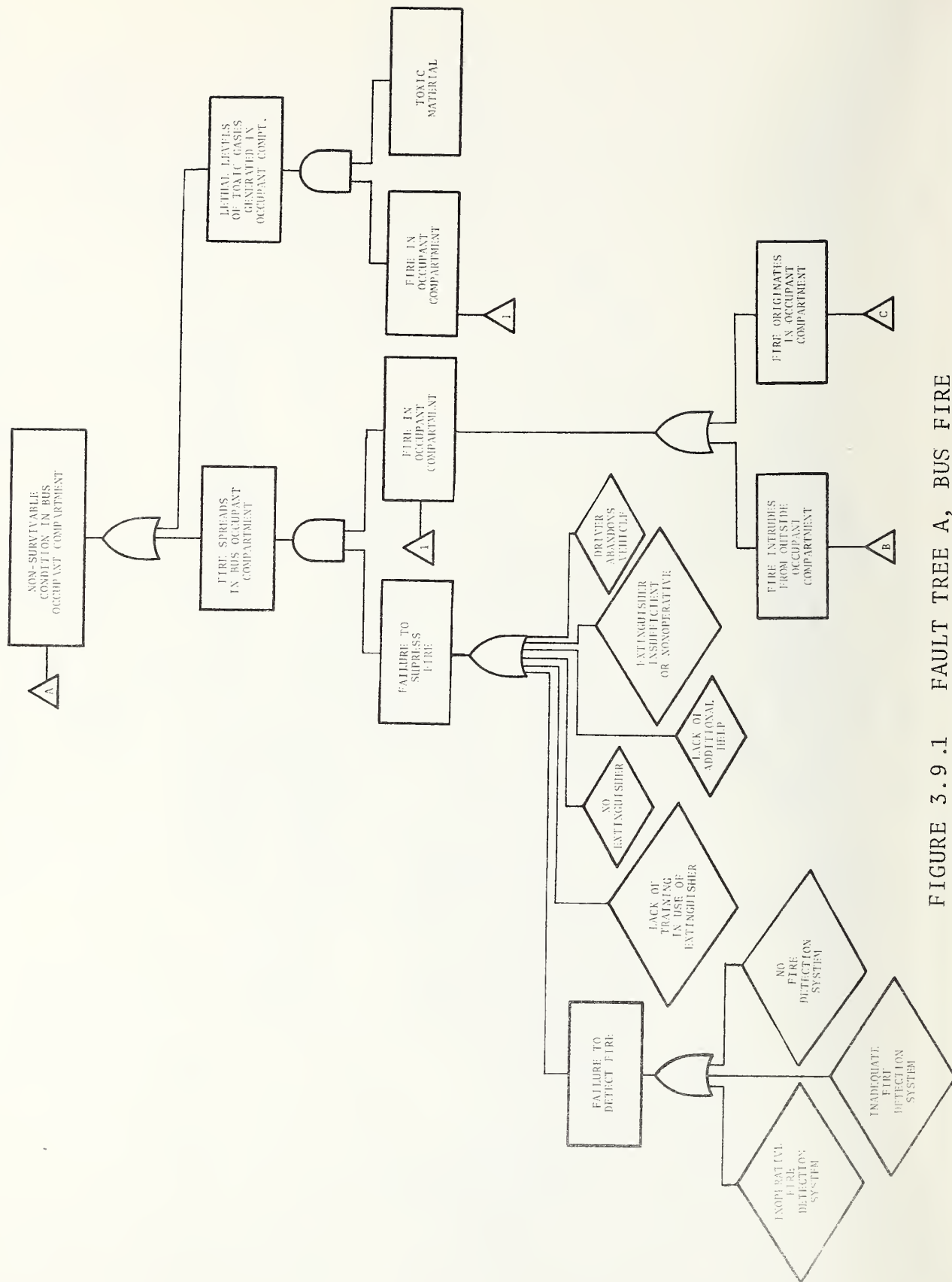
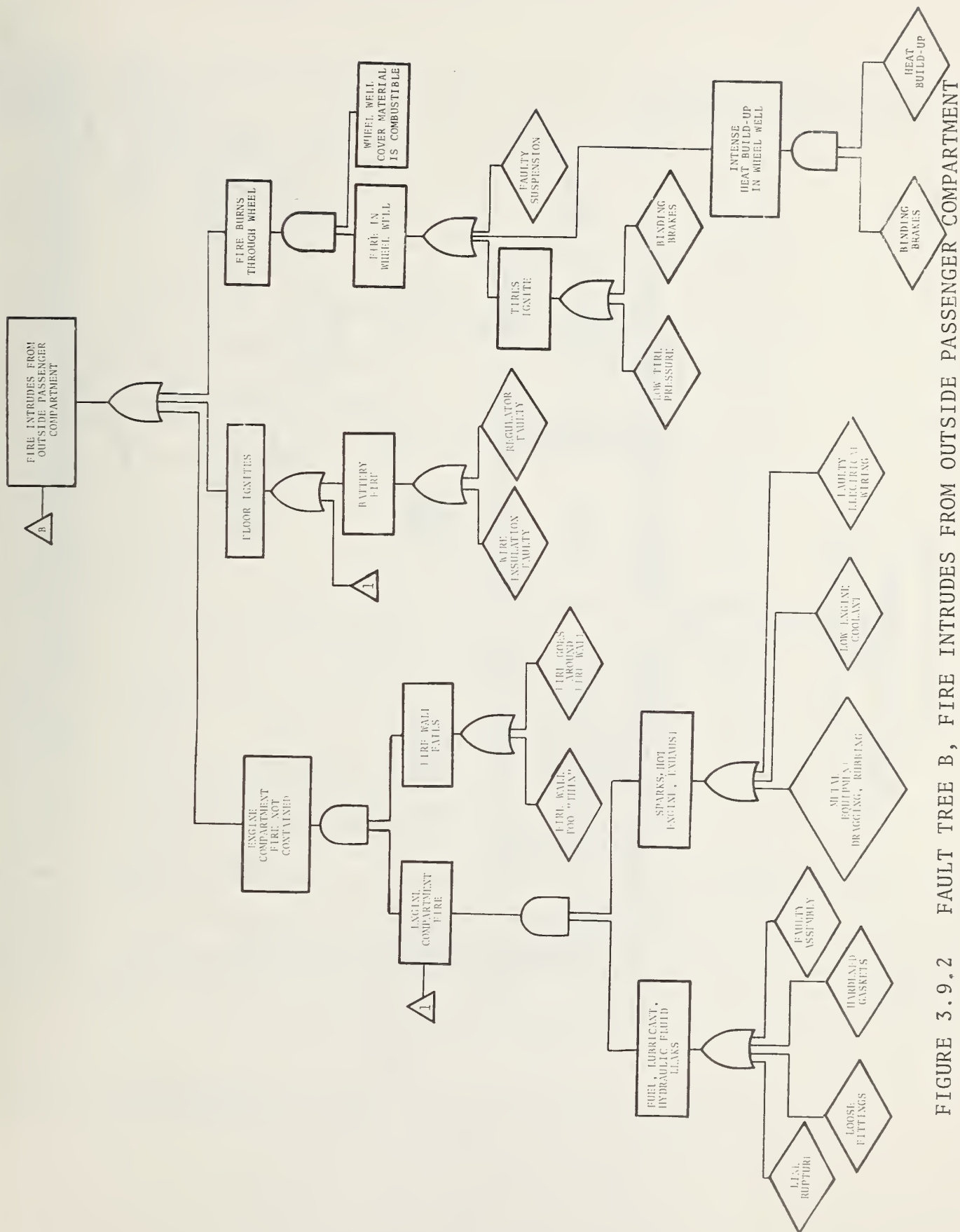


FIGURE 3.9.1 FAULT TREE A, BUS FIRE



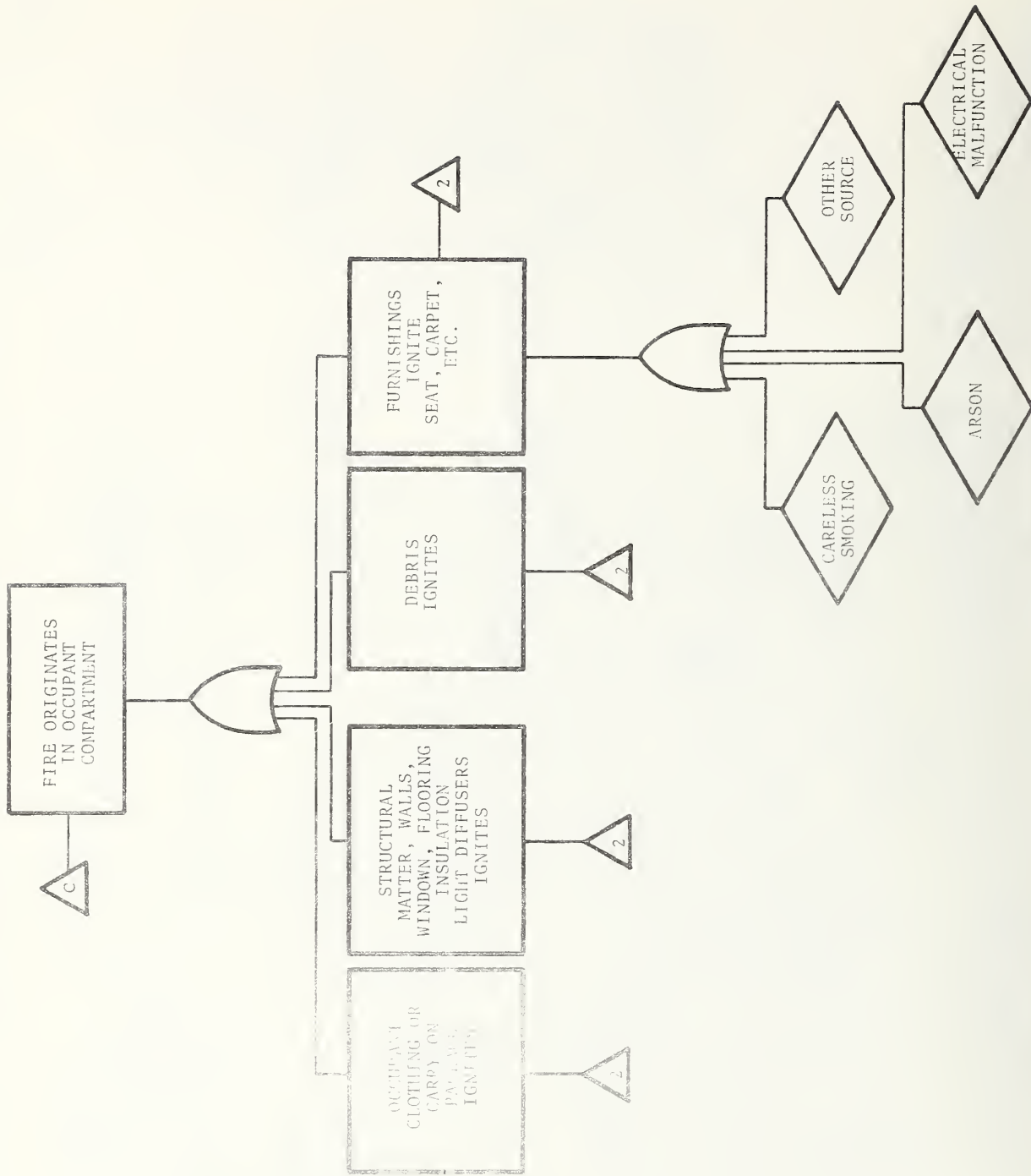


FIGURE 3.9.3 FAULT TREE C, FIRE ORIGINATES IN OCCUPANT COMPARTMENT

TABLE 3.1 RAIL RAPID TRANSIT SCENARIO TYPES

Scenario Number	Ignition Source	Incidents/Million Vehicle Miles	% of All Incidents
	(UNDERCAR FIRES)		
1	traction motor	1.3	24.5
2	resistor grid	0.54	10.2
3,4 5	defective brake control handbrake not fully released	0.44	8.3
6	switch failure	0.32	6.0
7 8	battery cable short metallic object lodged under car	0.29*	5.5
9	compressor	0.15	2.8
10	controller	0.14	2.6
11	journal	0.06	1.1
12	fuse	0.05	0.9
	(OCCUPANT COMPARTMENT FIRES)		
13 14 15	arson cigarette arson HVAC	0.02 0.06	0.4 1.1
16	defective lighting unit	-	-
	(WAYSIDE IGNITION FIRES)		
17	steel dust	0.12	4.3
			67.7
18, 19	Undetermined and miscellaneous**		32.3
			100.0

* Includes Scenario 16

**Vandals Drop Objects on Track, Equipment Cover on Track.

TABLE 3.2 BUS SCENARIO TYPES

Scenario Number	Ignition Source	Incidents/Million Vehicle Miles	% of All Incidents
	(WHEEL WELL FIRES)		
20, 21, 22 23 24	locked brake underinflated tire wheel bearing }	0.87	29.1
	(ELECTRICAL WIRING FIRES)		
25, 26 27 28 29	wiring short instrument panel lighting side panel }	0.69	22.9
	(LEAKING FUEL AND OIL FIRES)		
30 31, 32 33	fuel line leak oil leak oily residues }	0.31	10.3
	(ENGINE FIRES)		
34	engine	0.29	9.7
	(OCCUPANT COMPARTMENT FIRES)		
35 36, 37, 38	arson cigarette, etc.	0.21	7.0
	(EXHAUST FIRES)		
39	exhaust system	0.06	2.1
			81.1
40, 41	Undetermined and miscellaneous		18.9
			100.0

All of the scenarios developed are contained in Appendix B. Here, the scenarios are grouped according to general location on the vehicle or category of ignition source. Additional scenarios were developed which do not belong in the categories given in Figures 3.1 and 3.2. These were developed either because similar events had actually happened (at least once) or the possibility of their occurrence seemed plausible. These scenarios are intended to indicate the range of incidents which can and do occur on the RRT cars and transit buses. They are not intended to be exhaustive with regard to the variety of detail which may underlie each incident type. A general idea of ignition source at a more fundamental level is indicated in Table 3.3.

These concepts can be used in devising appropriate countermeasures to reduce the frequency of occurrence of specific categories of fire incidents. This is discussed below.

3.3 RELATIONSHIP OF DATA, SCENARIOS, AND FAULT TREES

As discussed in Section 3.1 the data on transit vehicle fire and smoke incidents, presented in Figures 3.1 and 3.2, represent the most detailed data available and provide an indication of where transit vehicle fire and smoke incidents occur and of the components involved. With this information it is then possible to rank the scenarios by their probability of occurrence and the service delay associated with that occurrence. Also, using the data on component fire and smoke incidents, the fault trees will show how the path of the fire or smoke may progress in the vehicle and possibly result in occupant death or injury. Furthermore, the fault tree may be

TABLE 3.3 VEHICLE HEAT SOURCES

Type	Source
Mechanical Friction	brakes bearings underinflated tires
Electrical	wiring shorts component shorts (starter, generator, motor, lighting, battery, switches, fuses, etc.) resistors
Engine Overheat	cooling system failure
Human Action	arson careless smoking, matches, etc.

evaluated in a quantitative manner if data are available which will indicate the probability of occurrence of each path in the fault tree and the probability of occurrence of the head event. Scenarios and fault trees may also be used in evaluating countermeasures before they are implemented. This may be done by inserting the proposed countermeasure in a scenario or fault tree and then evaluating it to see whether it has a significant effect. Probabilities and measures of hazard for the countermeasure may be determined through expert judgment, through its relationships to the conditions and events in the fault tree, and through an estimate to the degree of percentage improvement over the existing conditions.

4. METHODOLOGY FOR COUNTERMEASURE SELECTION

This section contains a brief summary of the approach for the development of countermeasures. A more detailed discussion of countermeasure development will be provided in a future report.

As noted in Section 3, each fire and smoke incident may have the potential of becoming a major incident resulting in injuries, fatalities and property losses. The judicious application of appropriate countermeasures will serve to reduce the tendency of minor fire incidents from developing into major conflagration and may, in some instances prevent the occurrence of any fire incident, entirely. The historical data identify where the incidents occur, the fault trees provide a description of the path of development each incident may take, and the scenarios provide a detailed description of events and actions taken by the occupants.

4.1 APPROACH TO COUNTERMEASURE DEVELOPMENT

Modern vehicle design practices have been directed at providing a safe and reliable service for passengers and operators. This approach has resulted in the increased use of non-metallic materials in transit vehicles and perhaps an increase in the fire threat associated with these vehicles. Historically, improvements in the fire protection of transportation vehicles have been directed at improving the construction by utilizing less flammable and toxic materials. However, this effort addresses only a portion of the problem; a comprehensive approach is needed that will include all factors contributing to the fire threat.

The proposed fire protection countermeasures for transit vehicles will encompass five major categories which are

applicable to new vehicle construction and retrofit programs:

Fire hazard analysis will involve the identification of meaningful test methods and utilization of screening/large-scale tests, the establishment of realistic fire safety criteria, and fire characterization by means of scaling and modeling studies.

Materials technology will encompass the development of new materials and the selection and improvement of conventional materials for a variety of applications, including thermal barriers, extinguishants, and personnel and vulnerable equipment protection.

Fire engineering will explore new concepts in fire containment, detection, smoke control, and emergency egress.

Operations and maintenance will provide for a review and updating of operating procedures, operating manuals, maintenance procedures and emergency training.

Fire fighting will involve the evaluation of extinguishing and personal protection equipment concomitant with training functions.

As shown in the "Logic Diagram for Countermeasure Selection," Figure 4.1, several countermeasures within each category are available for application to the identified fire threats.

4.2 EXAMPLES OF COUNTERMEASURES

Although the identification and selection of prospective countermeasures have just been initiated, several examples that appear worthy of further investigation are presented in this section.

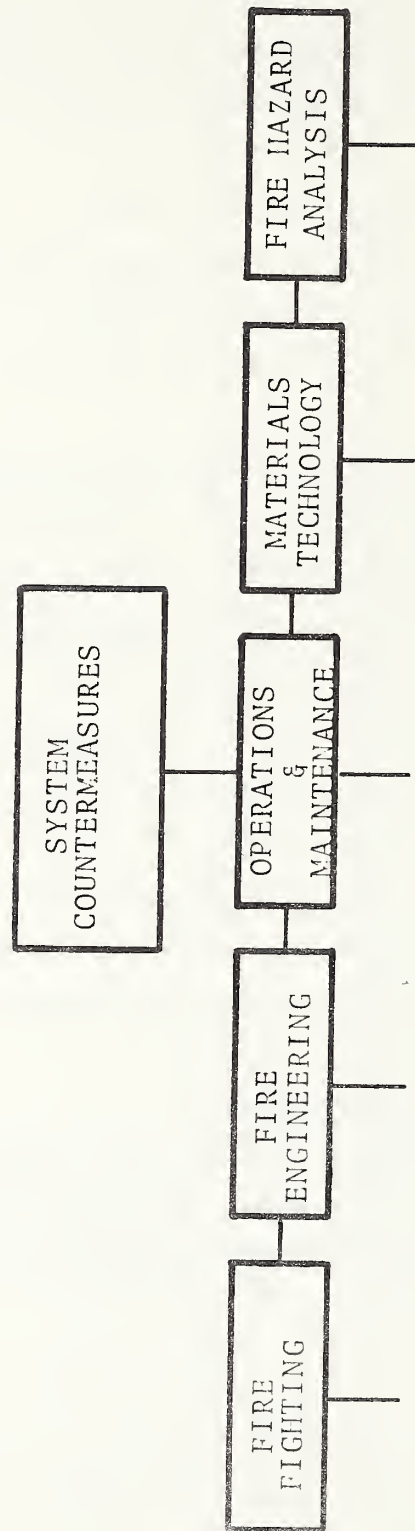


FIGURE 4.1 LOGIC DIAGRAM FOR COUNTERMEASURE SELECTION

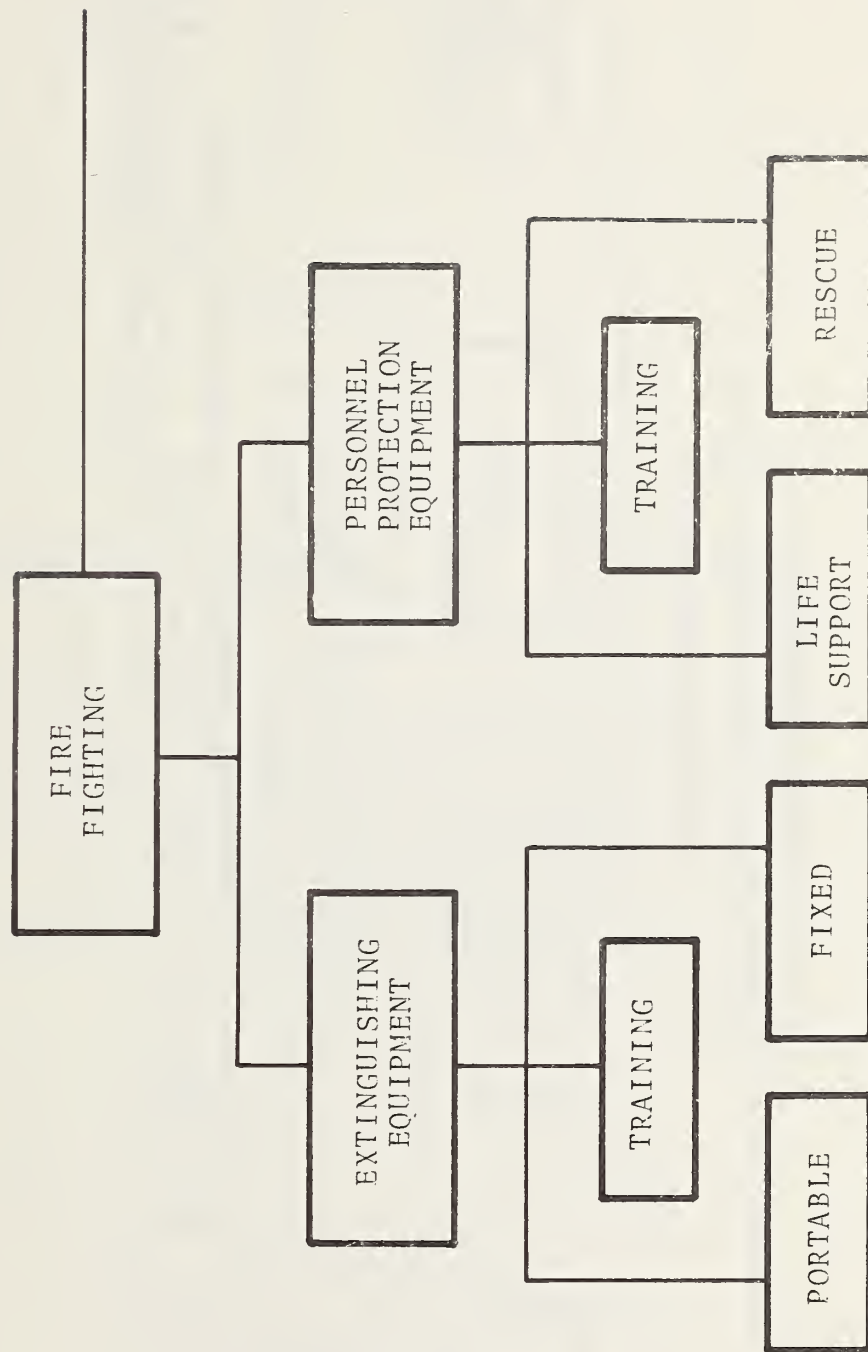


FIGURE 4.1 (CONTINUED)

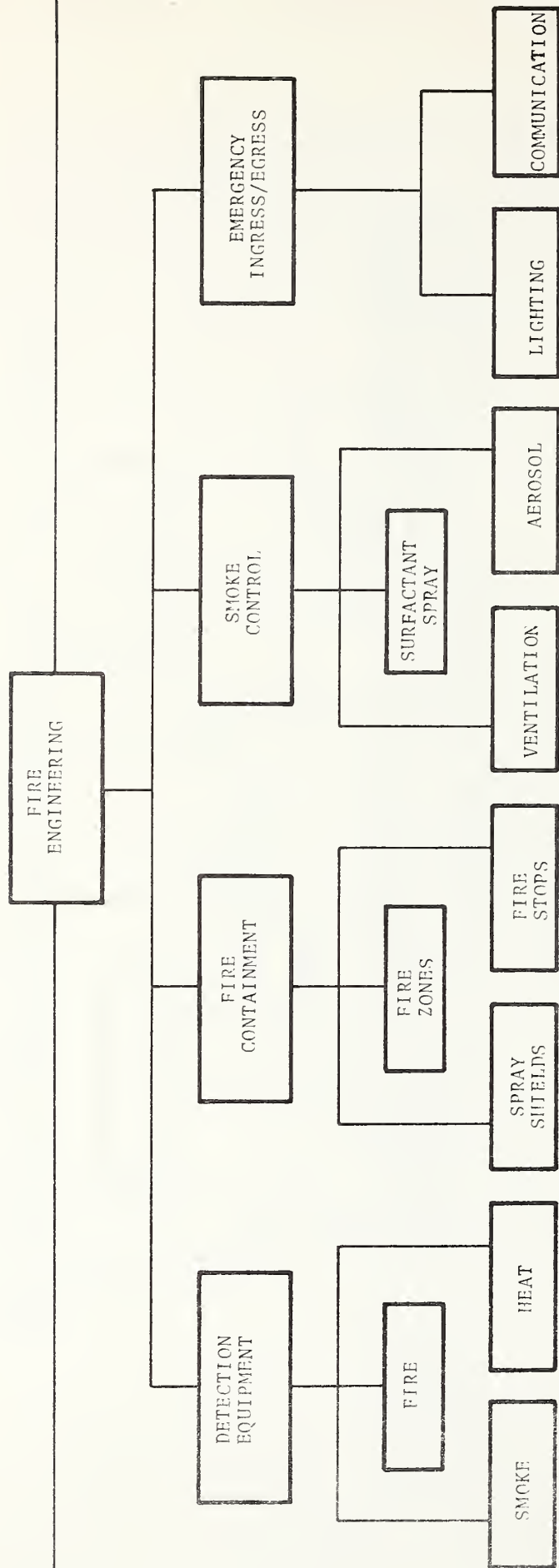


FIGURE 4.1 (CONTINUED)

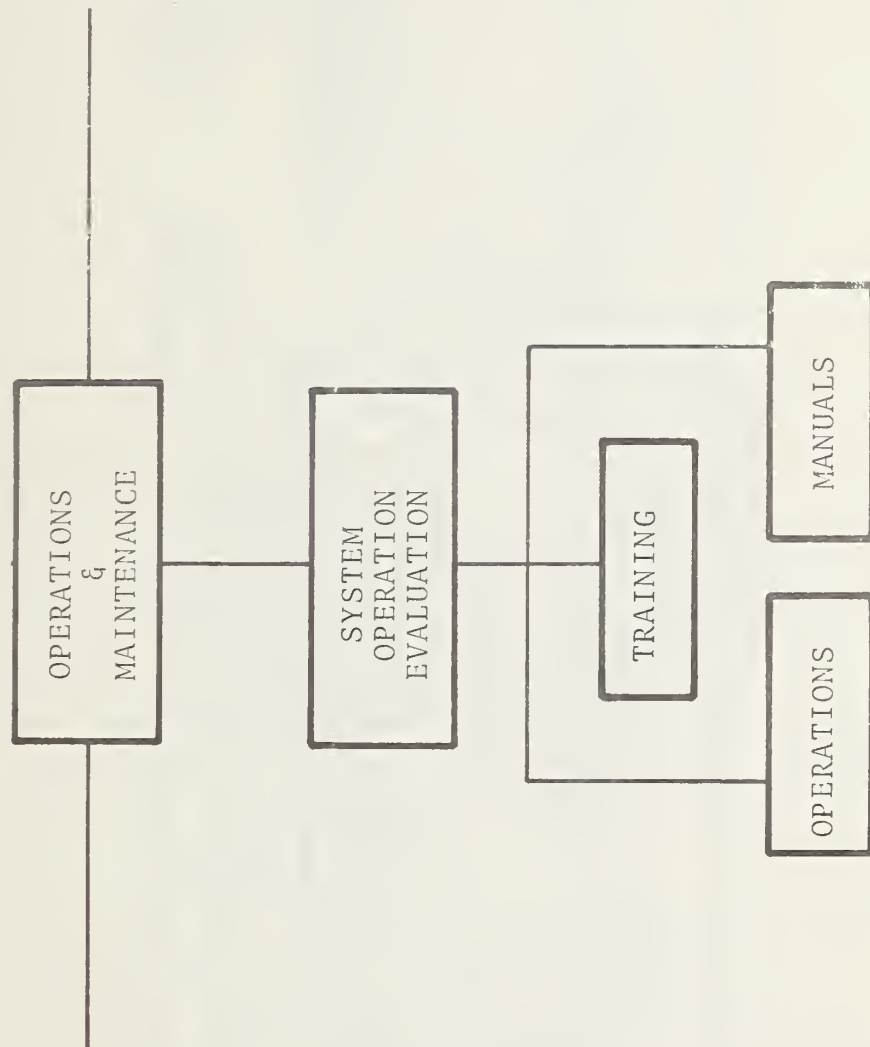


FIGURE 4.1 (CONTINUED)

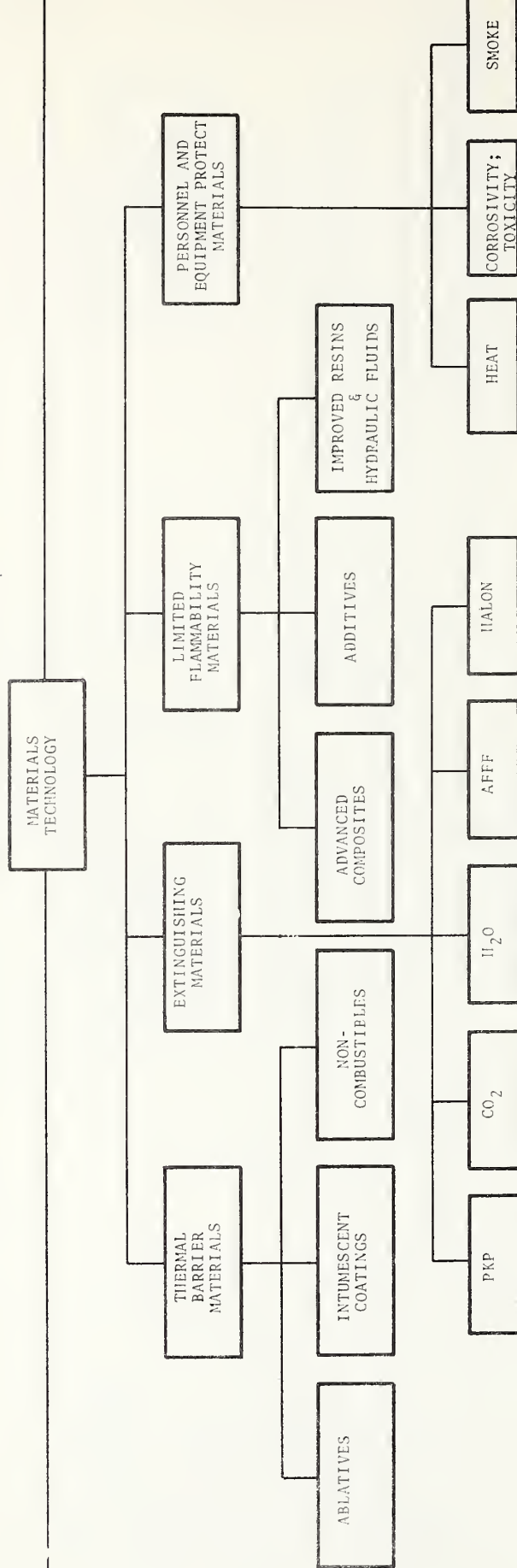


FIGURE 4.1 (CONTINUED)

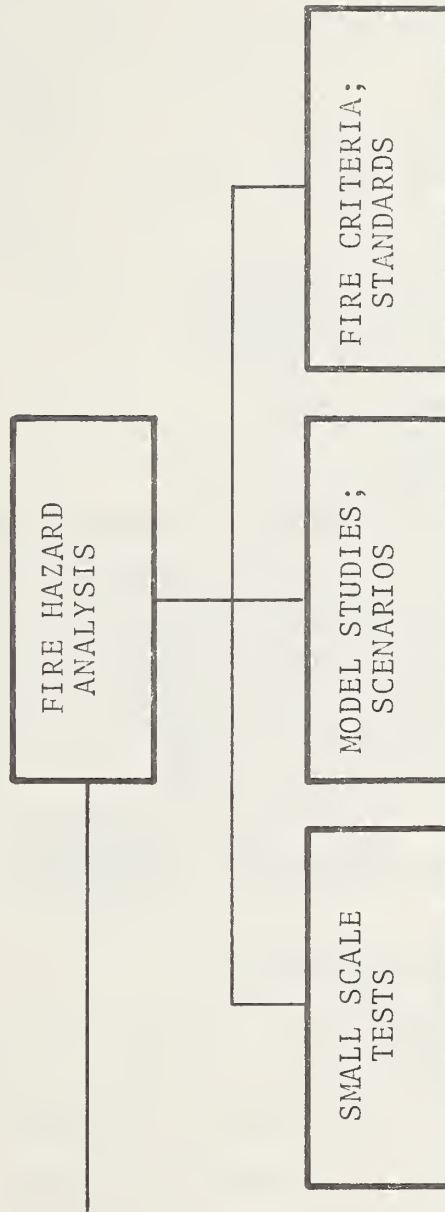


FIGURE 4.1 (CONTINUED)

4.2.1 Bus Wheel Wells

As shown in Table 3.2 fires in bus wheel wells accounted for 29.1 percent of all bus fire and smoke incidents. Scenario numbers 20, 21, 22, 23 and 24 are actual cases where wheel well fires have resulted in minor injuries and property loss. An effective countermeasure to prevent this problem could be a change in the wheel well material from a combustible material to a non-combustible material or a fire stop as shown in Figure 4.2. Several other methods, such as improved vehicle maintenance and inspection, are prospective countermeasures to deal with this problem.

4.2.2 Improved Vehicle Maintenance and Cleanliness

Deposits of grease, oil, metallic dust and other debris provide conditions where fires may be more easily ignited and propagated. Wires may become frayed and cause short circuits and arcing which results in fires and smoke. Improved maintenance and cleanliness are some of the principal countermeasures available. Lack of vehicle maintenance and cleanliness has been involved in the initiation of fire incidents.

4.2.3 Materials Technology

The proper selection of transit vehicle materials will minimize the fire threat by resisting ignition and fire propagation as well as minimizing smoke generation and subsequent obscuration. As shown in Figures 3.8 and 3.9, and the data collected from transit properties, materials in themselves do not cause ignition but do contribute to fire propagation and smoke generation. The materials countermeasures to be developed will be discussed in a future report.

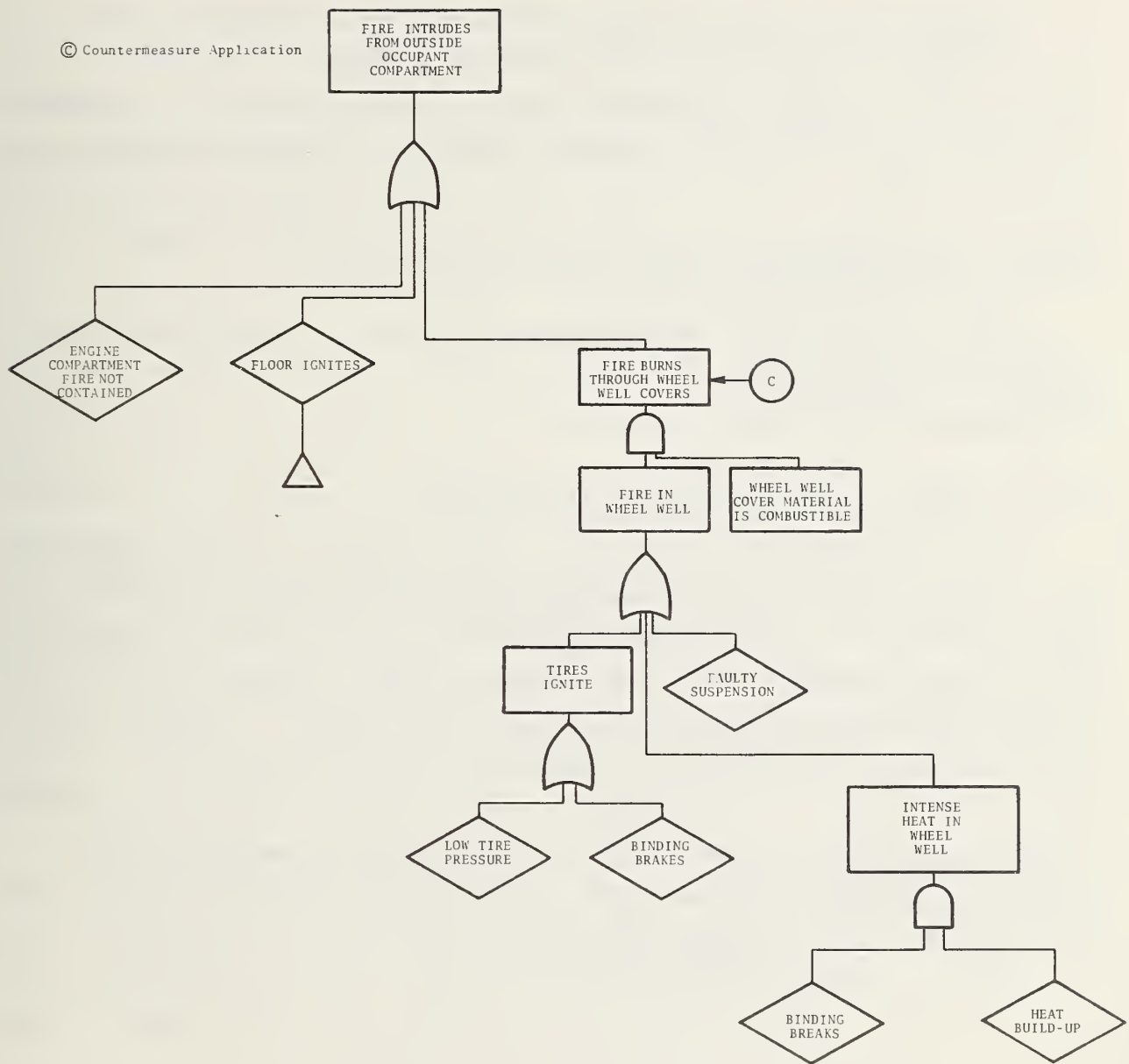


FIGURE 4.2 EXAMPLE OF APPLICATION OF COUNTERMEASURE AT BUS WHEEL WELL

4.2.4 Flooring and Firewall Construction

Rapid rail vehicle floors are often of a sandwich type in which plywood or polyurethane sheet is laminated between two metal sheets. This laminated construction possesses a superior strength-to-weight ratio and also provides insulation against undercar noise. Areas of the floor which may be exposed to fires originating in electrical undercar equipment should be further protected with heat-and-fire shielding.

Air-conditioning ducting should be fire-stopped and protected to prevent the penetration of fire and smoke into the passenger compartment.

4.2.5 Smoke and Fire Detection Devices

As noted in the rail rapid transit incident data, smoke and fire on the vehicle underside represent the majority of all incidents. In most instances the transit property operating personnel detect fire and smoke and take appropriate action before the incident develops any further. However, as noted in the scenarios, there have been cases where the initial incident has developed to major proportions and resulted in damage to the vehicle. Accordingly, consideration of the application of fire and smoke detectors under and in the vehicle may be appropriate.

5. CONCLUSIONS

Based on the data analyzed during visits to the transit properties and discussions with individuals in the transit community it is apparent that the rate of occurrence of fire and smoke incidents in transit vehicles is low relative to other types of incidents.

A major problem in studying urban mass transportation fires is availability of useful data. Records concerning fire and smoke incidents are not easily accessible. They are generally dispersed among records of transit property accidents, "unusual occurrences," or repairs. Descriptions of fire and smoke incidents usually are not explicit as to technical details or the extent of the damage, except in the case of special reports for major accidents. In most cases, it is not possible to follow an incident all the way to final disposition. Costs are not well documented; hence, cost/benefit estimation would be tenuous. Although it appears that most fire and smoke damage is of a minor or moderate nature and that incidents are relatively infrequent, better information on the severity of transit fires would be useful.

The foregoing is not intended to understate the potential that exists for severe hazards to life in those situations where fire fighting is difficult or where passenger escape is not straightforward; i.e., subsurface transit especially in underwater tubes.

REFERENCES

1. W.T. Hathaway and I. Litant, Assessment of Current DOT Fire Safety Efforts, UMTA-MA-06-0051-79-1, U.S. Dept. of Transportation, July 1979.
2. Willie Hammer, Handbook of System and Product Safety, Prentice-Hall, Englewood Cliffs NJ, 1972, p. 238.

APPENDIX A

FIRE AND SMOKE DATA FROM FRA/UMTA

REPORTING SYSTEM AND U.S. FIRE ADMINISTRATION

Data obtained from FRA thru Dec. 1978.
 Cut-off criteria for inclusion of incident:
 \$2300 equipment or 1 man day injury.
 Printout was searched for smoke-fire incidents;
 the following incidents were found:

<u>PROPERTY</u>	<u>DATE</u>	<u>CODE</u>	<u>PRIMARY CAUSE</u>	<u>COST</u>	
MBTA	8/1/75	474	Elec. Fire	\$20,672	
MBTA	11/30/75	706	Object on Track Causing Fire	\$19,881	
BART	5/14/76	474	Elec. Fire	\$5,250	
BART	11/17/76	702	Vandal Caused	\$100,000	
CTA	1/8/76	474	Elec. Fire	\$18,078	
CTA	1/17/76	475	Elec. Fire	\$20,351	
CTA	8/25/76	474	Elec. Fire	\$50,000	
MBTA	5/8/76	474	Elec. Fire	\$10,000	
MBTA	5/24/76	499	Unspec.	\$10,000	
MBTA	6/15/76	474	Elec. Fire	\$22,000	
MBTA	6/24/76	499	Unspec.	\$10,000	
MBTA	10/5/76	499	Unspec.	\$20,000	
BART	8/5/77	474	Elec. Fire	\$200,000	
BART	9/7/77	474	Elec. Fire	\$12,450	
CTA	1/14/77	475	Current Collector Syst.	\$28,000	
CTA	3/1/77	475	Current Collector Syst.	\$22,200	
CTA	11/26/77	799	Not Spec.	\$48,257	} 3 cars involved
CTA	11/26/77	799	Not Spec.	\$4,831	
CTA	11/26/77	799	Not Spec.	\$191,875	
MBTA	4/26/77	499	Not Spec.	\$3,170	
WMATA	5/12/77	474	Elec. Fire	\$11,600	
WMATA	7/6/77	474	Elec. Fire	\$9,000	
WMATA	7/11/77	474	Elec. Fire	\$10,000	
BART	1/5/78	474	Elec. Fire	\$5,965	
BART	5/30/78	702	Vandalism	\$3,678	
MBTA	5/18/78	449	Cause Code not listed	\$2,500	
BART	12/18/78	702	Vandalism	\$12,000	

1. RRT RAIL ACCIDENT/INCIDENT REPORT

FORM OF HEAT IGNITION							
UNKNOWN OTHER	HEAT SPARK, FROM LIQUID FUEL EQUIP.	HEAT, UNKNOWN, FUEL	HEAT ELEC ARC	HEAT OPEN FLAME SPARK	BACKFIRE, INTERNAL COMBUSTION ENGINE	INVALID	BLANK
2	1	1	7	1	2	-	-
2	4	4	1	4	2		



KEY:

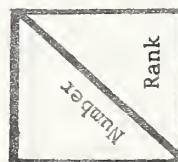
SOURCE: U.S. Fire Administration/NFIRS

States and Periods Covered:
 ALASKA CY77 & 1st Qtr 78
 MARYLAND CY77 & 2nd Qtr 78
 MINNESOTA CY77
 MISSOURI CY76, 1st Qtr 78
 NEW YORK CY75, CY76 (3rd & 4th Qtr)
 CY77, 1st Qtr 78
 OHIO CY76, CY77 (Corrected)
 1st Qtr 78
 OREGON CY77

2. FIRE INCIDENTS INVOLVING SELF-POWERED RAIL

TYPE OF MATERIAL IGNITED							
GASOLINE	OTHER COMBUSTIBLE FLAMMABLE LIQUID	POLYVINYL	OTHER PLASTIC	RUBBER	WOOD, PAPER	INVALID	BLANK
2	1	1	1	4	3	1	1
3	4	4	4	1	2		

Key:

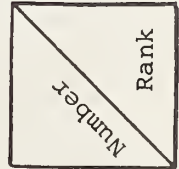


SOURCE: U.S. Fire Administration/NFIRS

States and Period Covered:
 ALASKA CY77 & 1st Qtr 78
 MARYLAND CY77 & 2nd Qtr 78
 MINNESOTA CY77
 MISSOURI CY76, 1st Qtr 78
 NEW YORK CY75, CY76, (3rd & 4th Qtr)
 OHIO CY77, 1st Qtr 78
 CY76, CY77 (Corrected)
 1st Qtr 78
 OREGON CY77

3. FIRE INCIDENTS INVOLVING SELF-POWERED RAIL

EQUIPMENT INVOLVED IN IGNITION									
UNKNOWN	HEAT TRANSFER SYSTEM	ELEC. DISTRIB. UNCL.	FIXED WIRING	ENGINE	RECTIFIER CHARGER	VEHICLE	NO EQUIP. INVOLVED	INVALID CODE	BLANK
1	1	1	1	2	1	3	1	-	2
3	3	3	3	2	3	1	3		



Key:

SOURCE: U.S. Fire Administration/NFIRS

States and Periods Covered:
 ALASKA CY77 & 1st Qtr 78
 MARYLAND CY77 & 2nd Qtr 78
 MINNESOTA CY77
 MISSOURI CY76, CY77, 1Qtr 78
 NEW YORK CY75, CY76 (3rd & 4th Qtr)
 OHIO CY77, 1st Qtr 78
 OREGON CY76, CY77 (Corrected)
 1st Qtr 78
 CY77

4. FIRE INCIDENTS INVOLVING SELF-POWERED RAIL



APPENDIX B

FIRE AND SMOKE SCENARIOS

NOTE: Scenarios based on incidents for which detailed reports were available are indicated by date of occurrence and property. The remaining scenarios are based on data indicating basic facts of incident but with few other details.

RAIL RAPID TRANSIT SMOKE AND FIRE INCIDENTS

UNDER CAR FIRES

FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L				
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	FIRE PROPAGATION	
FIRE EVENTS	Lack of lubrication at traction motor shaft causes excessive friction. Resulting heat buildup causes residual lubrication and cable insulation to smoke. Cable insulation ignites.	Under car wooden floor begins to smolder.	Fire department arrives at station 15 minutes after train arrives because it went to wrong station first. Fire department puts out fire.	Seats and side and ceiling panels around burning through in floor involved.
OCCUPANT EVENTS	Roadway inspector sees smoke coming from under car as train goes by. Inspector radios Central. Central radios the train operator and tells him to stop at next station (underground) and discharge passengers. (Central also calls fire department.)	Passengers get off at station.	Station fills with dense smoke. A number of bystanders at station hospitalized for smoke inhalation.	Service interruption - one hour. Car returned to maintenance department for repairs (severe fire damage).
OCCUPANT ATTENTION			OCCUPANT ACTIONS	TOXIC IMPACTS
				FIRE IMPACTS

1. RAPID RAIL FIRE - TRACTION MOTOR

FIRE INVOLVEMENT WITH OCCUPANT		FIRE PROPAGATION	
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L
<p>FIRE EVENTS</p> <p>Defective printed circuit on propulsion logic card causes full pressure to be applied to brake shoes of car.</p> <p>Overheating brakes ignite leaking brake fluid and wooden insulation blocks at 3rd rail pick-up shoe.</p>	<p>Heat and flames at brake shoe ignite undercar wiring and train line jumper cable causing train to stop.</p>	<p>Bystander sees smoke coming from train and calls fire department.</p>	<p>Hole burned through floor of car, seats in immediate area ignited.</p> <p>Fire extinguished before spread beyond first seats and walls around hole burned in floor.</p>
OCCUPANT EVENTS	Smoke and sparks first noticed by operator in train passing in opposite direction who informs Central Communications. Central notifies operator of Train with burning brakes.	Operator checks to be certain that there are no passengers in car, then assists in transferring passengers in other cars to another train which had drawn up on adjacent track.	None.
			Damage to seats and walls of car repairable. Brake pads and disks, hydraulic and pneumatic liner, electrical wiring, air bellows, evaporator box, and air conditioning ducts destroyed.
OCCUPANT ATTENTION		OCCUPANT ACTIONS	TOXIC IMPACTS
			FIRE IMPACTS

3. RAPID RAIL - BRAKE FIRE

FIRE INVOLVEMENT WITH OCCUPANT		FIRE PROPAGATION	
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L
Train operator applies hand-brake during emergency stop. He fails to fully release hand brake before getting underway again. Brake drum on drive shaft becomes heated to incandescence. Heat ignites lubrication on drive shaft bearing.	Fire from burning bearing lubrication spreads to oily dirt covering traction motor.	Train operator calls Central, then descends to track bed with fire extinguisher to put out fire.	N/A
OCCUPANT EVENTS	Occupants smell odor from dragging brakes while train is stopped at next station. Bystanders on station platform notify train operator of smoke from under the car.	Occupants get off train.	Minor irritation to eyes of bystanders by smoke
			Repairs to traction motor and armature shaft.
OCCUPANT ATTENTION		OCCUPANT ACTIONS	TOXIC IMPACTS
			FIRE IMPACTS

5. RAPID RAIL FIRE - HAND BRAKE NOT RELEASED

FIRE INVOLVEMENT WITH OCCUPANT				
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L	FIRE PROPAGATION
<p>FIRE EVENTS</p> <p>Train traveling through under- water tube during rush hour. Controller shorts to ground due to worn bushing. Heavy arcing ignites cable insula- tion. Heavy current draw blows main fuse. Train comes to stop.</p>	<p>Intense heat from burning cable insulation ignites greases and paint on nearby components.</p>	<p>Operator calls Central for help. Fire department arrives 30 minutes after train stops to fight fire.</p>	<p>Fire penetrates floor igniting floor material(asphalt tiles), seats (poly- urethane) side and ceiling panels (Kydex).</p>	<p>Fresh air from open doors increases intensity and rate of spread of fire within car. Flash- over does not occur.</p>
<p>OCCUPANT EVENTS</p>	<p>When train stops, tube begins to fill with smoke. Some passengers panic.</p>	<p>Passengers get down off of cars on to the track bed, some with difficulty and apprehension. Many experience breathing problems due to heavy smoke. Train crew directs passengers "up wind" towards fresh air. Some older passengers collapse.</p>	<p>Many passengers suffer smoke inhalation.</p>	<p>Many persons (passengers, crew, fire fighters) hospitalized for smoke inhalation and other fire related injuries - falls, burns, shock, etc. Car destroyed, tunnel damage severe, requiring 3 months shutdown to repair.</p>
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS

10. RAPID RAIL FIRE - CONTROLLER SHORT

OCCUPANT COMPARTMENT FIRES

**FIRE INVOLVEMENT
WITH OCCUPANT**

FIRE PROPAGATION

FIRE CONTROL

FIRE DEVELOPMENT

IGNITION

Flammable gases
liberated from
burning plastics
(partial pyrolysis)
flash over.

Fire spreads to
reinforced fiber-
glass ceiling; heat
nearby seats and
burns carpeting and
floor insulation.

Central
Communication
calls fire
dept. and next
above ground
station to
prepare them
to deal with
fire.

Burning newspaper
burns through nylon
seat cover and
ignites polyurethane
foam cushion.

Arsonist ignites crumpled
newspaper on seat (last
car) of Train.

**FIRE
EVENTS**

Interior of car
excluding atten-
dants' compartment
and last 8 seats
destroyed. Ex-
terior and under-
car not damaged.

None

Operator drives
train to next
above ground
station to get
passengers off
train and deal
with fire.

Train operator notified of
fire by passengers on next
car over intercom moments
after leaving Station.
Central Communications
calls train operator to
advise him of a report
from a bystander that there
is a fire in the last car.

**OCCUPANT
EVENTS**

**OCCUPANT
ACTIONS**

OCCUPANT ATTENTION

13. RAPID RAIL FIRE - ARSON

FIRE EVENTS	FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L				FIRE PROPAGATION	
	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL			
FIRE EVENTS	Arsonist ignites fire on cushioned seat of last car in six-car train travelling in tunnel.	Fire develops rapidly because of highly combustible nature of latex foam seat cushions. Very heavy smoke development almost immediately.	Fire observed by passing motorman who calls Central Control. Latter tell motorman to stop train at next station. Firemen unable to enter station because of smoke and heat, proceed to next station and along tracks to burning vehicle.	Fire was seen to spread from burning seat cushion up wall and over ceiling to doorway. other side of car. Acrylic lighting covers contributed to the overall heat load.	Fire moved from one car to next through car-end doorways.	
OCCUPANT EVENTS	Only seven passengers on this last train for the night, at 1:45 AM. Notified by public address system to leave train.		Passengers exit train at station. Attempts to leave station via stairway frustrated by heavy smoke already in station mezzanine. Passengers leave station along tracks.	One passenger found unconscious on station platform and removed to safety. Two passengers hospitalized for smoke inhalation.	Three cars completely destroyed, their aluminum shells almost entirely melted. A fourth car damaged beyond repair.	
	OCCUPANT ATTENTION		OCCUPANT ACTIONS		TOXIC IMPACTS	FIRE IMPACTS

14. RAPID RAIL FIRE - ARSON

WAYSIDE IGNITION FIRES

MISCELLANEOUS FIRES

FIRE EVENTS	FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L				FIRE PROPAGATION			
	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L	FIRE PROPAGATION			
	Vandals drop automobile hubcaps down onto rapid transit rail tracks from street above tunnel opening trying to cause shorting of 3rd rail. Train comes out of tunnel and hubcap lodges under car causing arcing near wooden insulator blocks. Insulator blocks ignite.	Arcing continues as the burning insulator block gets hotter. Fire spreads to wiring insulation near insulator block and wooden floor near insulator blocks.	Woman sees arcing, smoke, and flame from street and calls Fire Depart- ment. Fire Department calls Transit Co.	Fire burns hole in plywood floor and ignites seats immediately above hole.	Flammable vapors liberated from polyurethane cushions flash over near ceiling; radiation heat ignites ceiling, wall and the rest of the seats. Outside of car blackened.			
OCCUPANT EVENTS	Transit Co. notifies operator over radio. Operator notifies passengers over car speakers.	Operator orders passengers out of the burning car into adjacent car and proceeds to next station where passengers get off.	Operator and several firemen suffer smoke inhalation.	Interior of car destroyed.				
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS				

18. RAPID RAIL FIRE - VANDALISM

BUS FIRE AND SMOKE INCIDENTS

WHEEL WELL FIRES

COMPARTMENT MAT'L

20. BUS FIRE - BRAKE

PAST INCIDENTS	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS
<p>Pressure release valve malfunction on rear brake causes brake to drag which results in brake drum becoming heated to cherry red color (1000°F). Conduction and radiation of heat from drum to surrounding wheel and to axle. Plastic grease seal fails due to heat; axle grease leaks out onto hot wheel and ignites. Tire ignites and further heats wheel well.</p>	<p>Heat from wheel well ignites fiberglass reinforced plastic polyester wheel well.</p>	<p>Fire - fire extinguisher missing.</p>	<p>Fire breaks through plastic wheel well. Thick smoke outside of bus from wheel well. Seat above wheel well ignites. Dense smoke rises to ceiling. Seat burns intensely. Heat generated rises up and horizontally. Neighboring seats ignite.</p>	<p>Heat and flammable vapors at ceiling ignite melamine ceiling material. Fire spreads forward to open doors. Hot air and smoke pour from high part of open doors. Fresh air enters lower part of open doors to feed flames.</p>
<p>Bus 60% full. Passenger seated on rear seat notices smoke but believes it is from "smoky" exhaust.</p>	<p>Passenger seated over wheel well notices heat and alerts adjacent passengers.</p>	<p>Passengers at rear of bus notify driver and move away from wheel well. Driver stops bus to investigate. Passengers get off bus when he finds fire and smoke became too intense to deal with.</p>	<p>Choking smoke and fumes have driven passengers and driver from bus.</p>	<p>Fire Department notified by passing CB operator. Fire truck arrives 10 minutes later to put out fire. Bus already a burned shell because of rapid burning of seats and evolved flammable vapors. Passengers shaken but not injured. One elderly lady had to be helped off of the bus. Traffic on bus side of artery stopped for 30 minutes.</p>

FIRE EVENTS	FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L				
	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	FIRE PROPAGATION	
FIRE EVENTS	Brake on rear right wheel locks; heat on drum builds to 1200°C. A load bang due to metal fracturing or tire exploding alerts driver and passen- gers. Tires begin to smolder. A few minutes later, tires are ignited.	Fire and heat ignites plastic wheel well.	None. Plastic wheel well will not con- tain fire; fire extin- guisher not on board.	Fire penetrates plastic wheel well and ignites seat above wheel well.	Wall, ceiling, and nearby seats begin to burn.
OCCUPANT EVENTS	Driver stops bus to investigate loud bang. He gets off bus and examines wheel area and sees smoke coming from wheel well. He returns to bus to order passengers off. On returning back to wheel well, tires ignite.		Passengers leave bus; driver finds that fire extin- guisher is not present. Driver calls fire depart- ment from nearby house.	N/A	Repair cost: \$5,149.11
	Scenario Verified.				
	Incident:				
	Queen City Metro, 11/12/75				
FIRE EVENTS					
OCCUPANT ATTENTION				OCCUPANT ACTIONS	FIRE IMPACTS
				TOXIC IMFACS	

21. BUS FIRE - BRAKE

FIRE INVOLVEMENT
WITH OCCUPANT
COMPARTMENT MAT'L

IGNITION

FIRE DEVELOPMENT

FIRE CONTROL

FIRE PROPAGATION

Outside rear wheel deflated by vandals placing too high a load on inner tire which overheats. Heavy load placed on brakes due to rapid deceleration of loaded bus on steep downgrade. Brakes overheat to ~1000°F. Inner tire begins to smoke, temperature within wheel well approaches ignition temperature of fiberglass reinforced plastic wheel well and smoke particles. Wheel well ignites.

Ignited plastic wheel well gives off flammable vapors which remain in wheel well. Flammable vapors burn raising temperature of wheel well to point at which vigorous burning commences.

No action by bus driver possible in time to prevent fire from spreading because of delay caused by rush of passengers quickly fill overhead space of bus. By the time driver can investigate, fire is firmly established in occupant compartment.

Flames and bits of flaming plastic quickly ignite seat facing wheel well, then seat over wheel well. Smoke and flammable vapors from seat fire quickly fill overhead space of bus.

Hot air pouring out of open doors replaced by fresh air pouring in through lower part of open doors. Fresh air feeds seat fire which in turn evolves more flammable vapors which burn at ceiling consuming melamine lining and melts aluminum exterior of bus.

All seats filled, standees crowd aisle of bus from front to rear. Woman sitting on seat, facing wheel well first notices high heat from wheel well. Flames break through wheel well in front of woman.

Woman screams as bits of flaming plastic fall on her legs. Passengers in wheel well area shouting "Fire!" and crowd away from wheel well area. Woman with scorched legs half dragged away as driver stops bus and opens doors.

All passengers escape toxic vapors evolved from burning plastic seat covers, seat cushions, and plastic wheel well. Bus driver inhales smoke and toxic vapors when he goes to rear to investigate same. He escapes just in time.

One woman with painful burns on lower legs. One young boy injured by crush of people leaving bus through rear door.

One woman suffers broken arm after fall from being pushed off bus steps by crowd.

Bus driver suffers smoke inhalation.

OCCUPANT
EVENTS

OCCUPANT ATTENTION

OCCUPANT
ACTIONS

TOXIC
IMPACTS

FIRE IMPACTS

FIRE
EVENTS

23. BUS FIRE - TIRE

ELECTRICAL WIRING FIRES

FIRE EVENTS	FIRE INVOLVEMENT WITH OCCUPANT				FIRE PROPAGATION	
	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L		
FIRE EVENTS	Wire to automatic transmission becomes shorted and overheats to 1000°F. Ignites wire bundle. There are no passengers on the bus.	Heat in engine compartment builds rapidly causing rear control box to melt.	Fire wall under rear seat contains fire until fire department arrives to put out fire.	Fire put out while still contained in engine compartment.	N/A	
OCCUPANT EVENTS	Driver sees in the rear view mirror smoke coming from rear (exterior) of bus. Passing motorist notices smoke and calls fire department.		Driver stops bus and goes to rear to investigate. After seeing that smoke is coming from engine compartment, driver goes to get fire extinguisher and finds it inadequate for putting out fire.	N/A	N/A	
Scenario Verified. Incident: WNATA, 11/20/76						
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS		

25. BUS FIRE - WIRING

**FIRE INVOLVEMENT
WITH OCCUPANT**

IGNITION

FIRE DEVELOPMENT

FIRE CONTROL

WITH OCCUPANT
COMPARTMENT MAT'L

FIRE PROPAGATION

Insulation on wiring behind instrument panel breaks down due to excessive heat caused by poor electrical contact at junction block. Resulting shorts cause wiring to smolder and ignite.

Smoldering fire develops behind instrument panel.

Bus driver
puts out fire
with on-board
extinguisher.

None

None

FIRE EVENTS

OCCUPANT EVENTS

Occupants notice fire at same time driver notices fire

None

None

Bus removed from
service 1 day.

OCCUPANT ATTENTION

OCCUPANT ACTIONS

TOXIC IMPACTS

FIRE IMPACTS

**FIRE INVOLVEMENT
WITH OCCUPANT
COMPARTMENT MAT'L**

**FIRE INVOLVEMENT
WITH OCCUPANT
COMPARTMENT MAT'L**

LEAKING FUEL AND OIL FIRES

FIRE INVOLVEMENT
WITH OCCUPANT

	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L	FIRE PROPAGATION
FIRE EVENTS	Driver pulls out of yard for morning run. Fitting connecting fuel line to injector is loosened by vibration.	Gas continues to leak from loose fitting, feeding the flames. Fresh air keeps the fire growing.	Fire extinguisher missing from bus. Small fire	Heat from engine compartment starts fiber glass reinforcing rear seats	Fire quickly consumes last few rows of seats, the ceiling and rear floor.
	Fuel leakage is slight but vibration continues to loosen fitting. Engine compartment fills with fumes. At 6:45 AM 20 passengers are picked up. At about 6:55 AM heat from the exhaust manifold causes the fumes to ignite.		extinguisher from State Trooper's car inadequate to fight fire. Onlooker at overpass pulls fire call box lever.	and paint to smoke, filling interior of bus. Aluminum fire wall melts and fire quickly spreads to interior of bus.	
OCCUPANT EVENTS	At about 7:00 AM driver looks into rear-view mirror and sees grey smoke to the rear of the bus. Passengers not yet aware of smoke.	Driver stops bus and orders passengers off. Interior of bus fills with smoke. State Trooper on traffic duty arrives and tries to fight fire with small fire extinguisher from his car.	Bus is empty of people as toxic smoke and vapors fill interior of bus.	Traffic stopped on highway for one hour. No personal injury. Passengers get rides with passing motorists.	
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS	

30. BUS FIRE - FUEL LEAK

FIRE INVOLVEMENT WITH OCCUPANT		FIRE DEVELOPMENT		FIRE CONTROL		FIRE PROPAGATION	
IGNITION		FIRE DEVELOPMENT		FIRE CONTROL		FIRE PROPAGATION	
FIRE EVENTS	Oil leaking from faulty valve cover gasket vaporizes as it runs down towards exhaust manifold filling engine compartment with flammable vapor.	Ignited vapors raise temperature in engine compartment. Oil which covers much of the engine ignites; rubber hoses and plastic insulators and parts begin to burn with intense heat.		Bracket holding fire extinguisher had cut through fire extinguisher tank due to vibration several months after bus was first put into service. Fire extinguisher useless.		Temperature in engine compartment rises to 1200°F. Aluminum fire wall near melting point. Heat transferred by radiation to rear seat (polyurethane with neoprene cover); rear seat begins to smolder, filling bus with dense smoke.	
	Loose terminals on alternator allows cable connection to vibrate causing sparks.					Fire wall melts and rear seat, already very hot, bursts into violent flames due to added heat and air from engine compartment. Rear floor area and ceiling ignite. Radiation ignites remaining seats towards rear of bus.	
	Spark ignites oily vapors.						
	Time: 6:40 AM.						
OCCUPANT EVENTS		No passengers on bus. Driver is not aware of fire until interior filled with smoke from smoldering seats near fire wall. Operation of bus does not indicate presence of problems.		Driver looks for fire call box. Failing to see one, driver stops bus at small store which is open. Driver removes fire extinguisher but finds hole worn through side of cylinder due to rubbing against retaining bracket. Driver runs into store to call fire department.		Driver suffers smoke inhalation and eye irritation. out fire.	
Scenario Verified. Incident: MBTA, 2/14/78							
OCCUPANT ATTENTION				OCCUPANT ACTIONS		TOXIC IMPACTS	
						FIRE IMPACTS	

31. BUS FIRE - OIL LEAK

FIRE EVENTS	FIRE INVOLVEMENT WITH OCCUPANT				
	IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L	FIRE PROPAGATION
OCCUPANT EVENTS	Presence of oil throughout engine compartment due to leaky gaskets and fittings leads to spontaneous ignition of "caked on" oil with a loud "bang".	Burning oil near exhaust manifold raises temperature of "caked on" oil nearby driving flammable vapors into the air in the engine compartment. A second explosion occurs. Fire becomes very intense.	Thin aluminum fire wall lined with 1/4" fiberglass.	At second explosion, rear of passenger compartment in flames.	Entire bus quickly engulfed in flames.
	At sound of first explosion, driver stops bus and orders passengers (15) off. A second explosion occurs.		Passengers get off bus just in time before second explosion occurs, and rear of bus becomes engulfed. Driver forced to leave bus also.	N/A	Bus total wreck. \$80,000
	Scenario Verified.				
	Incident: Bi-State, 1/26/78				
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS	

33. BUS FIRE - OIL RESIDUES

ENGINE FIRES

OCCUPANT COMPARTMENT FIRES

FIRE INVOLVEMENT WITH OCCUPANT COMPARTMENT MAT'L					
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	FIRE PROPAGATION		
FIRE EVENTS	Careless passenger drops lit cigarette on floor in front of his seat. Cigarette rolls forward against small paper bag containing a leaky can of lighter fluid which had been inadvertently dropped by passenger in forward seat. Lighter fluid soaked paper ignites and burns rapidly.	Rapidly burning bag ignites nylon seat cover. Heated can of lighter fluid ruptures causing fire to flare up and spread suddenly.	On board fire extinguisher inadequate to deal with burning polyurethane seats. Fire department arrives 8 minutes after being called by police car.	Flames under seat ignite polyurethane seat cushion.	Fire spreads rapidly from seat cushion to melamine wall panel, ceiling, and plastic lighting lenses.
OCCUPANT EVENTS	Bus fully loaded. Passengers near rapidly expanding fire panic, pushing away from fire.	Driver stops bus and opens doors, grabs fire extinguisher and tries to push his way towards fire. Large truck stops on right side and very close up to bus impeding exit of passengers.	Twenty-five passengers and bus driver suffer smoke inhalation.	Interior of bus gutted. Eight passengers injured in crush to exit bus. One passenger suffers heart attack and dies later that day.	
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS	

37. BUS FIRE - CIGARETTE

FIRE INVOLVEMENT WITH OCCUPANT		FIRE PROPAGATION			
FIRE		FIRE DEVELOPMENT		FIRE CONTROL	
EVENTS		FIRE DEVELOPMENT		FIRE CONTROL	
IGNITION		FIRE DEVELOPMENT		FIRE CONTROL	
FIRE EVENTS	Bus stops to pick up man on his way to his car with a can of gasoline and sits down behind driver next to a man with a pipe in his mouth. The man with the pipe takes the pipe from his mouth; it slips from his grasp and falls to the floor next to the can of gasoline. A small spark from the pipe bowl ignites the fumes around the vent hole of the gasoline can.	Plastic vent hole fitting ignites. Gasoline can falls over and gasoline spills out, the fires flare up in the middle of the floor.	Bus driver pulls out fire extinguisher and puts out fire.	Rubber floor runner scorched.	N/A
OCCUPANT EVENTS	Man sitting with gasoline can at his feet sees plastic vent hole burning; in his excitement he kicks can over in trying to get it away from him.	Man sitting with gasoline can at his feet sees plastic vent hole burning; in his excitement he kicks can over in trying to get it away from him.	Driver opens both doors and passengers hurry out.	N/A	Minor damage to floor of bus. One passenger sprains ankle in haste to get off bus.
		OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS

38. BUS FIRE - PASSENGER CARRY-ON

EXHAUST FIRES

FIRE INVOLVEMENT WITH OCCUPANT		FIRE PROPAGATION	
IGNITION	FIRE DEVELOPMENT	FIRE CONTROL	COMPARTMENT MAT'L
FIRE EVENTS Exhaust pipe ruptures at exhaust manifold connection. Hot exhaust gases heat and ignite oil leaking from valve cover.	Burning oil raises temperature engine compartment; hoses and wire insula- tion ignite.	On-board fire extinguisher is used to prevent fire in engine compartment from getting worse.	While driver is fighting fire with extinguisher at engine compartment, aluminum fire wall melts and rear seats ignite. Rising heat at rear of bus ignites melamine ceiling. Radiated heat ignites additional rear seats. Rear (polycarbonate) windows melt.
OCCUPANT EVENTS	Driver looks in rear view mirror and sees black smoke billowing from rear of bus. Simultaneously, passengers on rear seat notice sudden heat build-up and notify driver.	Driver stops bus and orders passengers off. One of the passengers calls fire department from nearby phone booth.	Fire department personnel suffer smoke inhalation.
			Most of interior of bus destroyed. Engine destroyed.
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPAIRMENTS
			FIRE IMPACTS

39. BUS FIRE - ENGINE - EXHAUST PIPE RUPTURE

MISCELLANEOUS FIRES

FIRE INVOLVEMENT
WITH OCCUPANT

COMPARTMENT MAT'L

FIRE DEVELOPMENT

FIRE CONTROL

FIRE PROPAGATION

IGNITION

FIRE
EVENTS

Shaft of defective air conditioner alternator siezes causing alternator to overheat. Alternator and wiring insulation ignite.

Water hoses above alternator become hot and begin to smoke.

Driver extinguishes fire with on-board extinguisher.

None

None

OCCUPANT
EVENTS

Passengers at rear of bus notice smoke coming out of engine compartment when bus stops at a bus stop.

Passengers notify driver who stops bus; passengers get off. Driver takes on-board extinguisher to engine compartment.

None

Burned alternator and wires.

OCCUPANT ATTENTION

OCCUPANT
ACTIONS

TOXIC
IMPACTS

FIRE IMPACTS

40. BUS FIRE - A/C ALTERNATOR

FIRE EVENTS	FIRE DEVELOPMENT		FIRE INVOLVEMENT WITH OCCUPANT		FIRE PROPAGATION	
	IGNITION		FIRE CONTROL	COMPARTMENT MAT'L		
FIRE EVENTS	Bus stops at stop light on heavily traveled street. Speeding truck approaches bus from rear and is unable to stop before colliding with rear end of bus. Bus (gasoline engine) gasoline line is ruptured at the carburetor, carburetor bowl also ruptured. Spilled gasoline is ignited on hot exhaust manifold.	Oily residues in engine compartment and electrical insulation begin to burn.	Driver of truck and bus driver quickly extinguish engine fire with on-board fire extinguisher.	N/A	N/A	
OCCUPANT EVENTS	Shock of collision alerts driver and passengers.		Passengers leave bus unhurt. Driver goes to look at damage and sees flames. He goes to get fire extinguisher. Together with truck driver, they put out fire which has not yet gotten out of hand.	N/A	Minor fire damage to engine.	
	OCCUPANT ATTENTION	OCCUPANT ACTIONS	TOXIC IMPACTS	FIRE IMPACTS		

41. BUS FIRE - COLLISION

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